

EOS-A

(NASA-TM-109395) APPLICATIONS OF
SPACE-AGE TECHNOLOGY IN
ANTHROPOLOGY (NASA) 251 p

N94-71223
--THRU--
N94-71237
Unclass

Z9/54 0201787

APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

*November 28, 1990
Conference Proceedings*

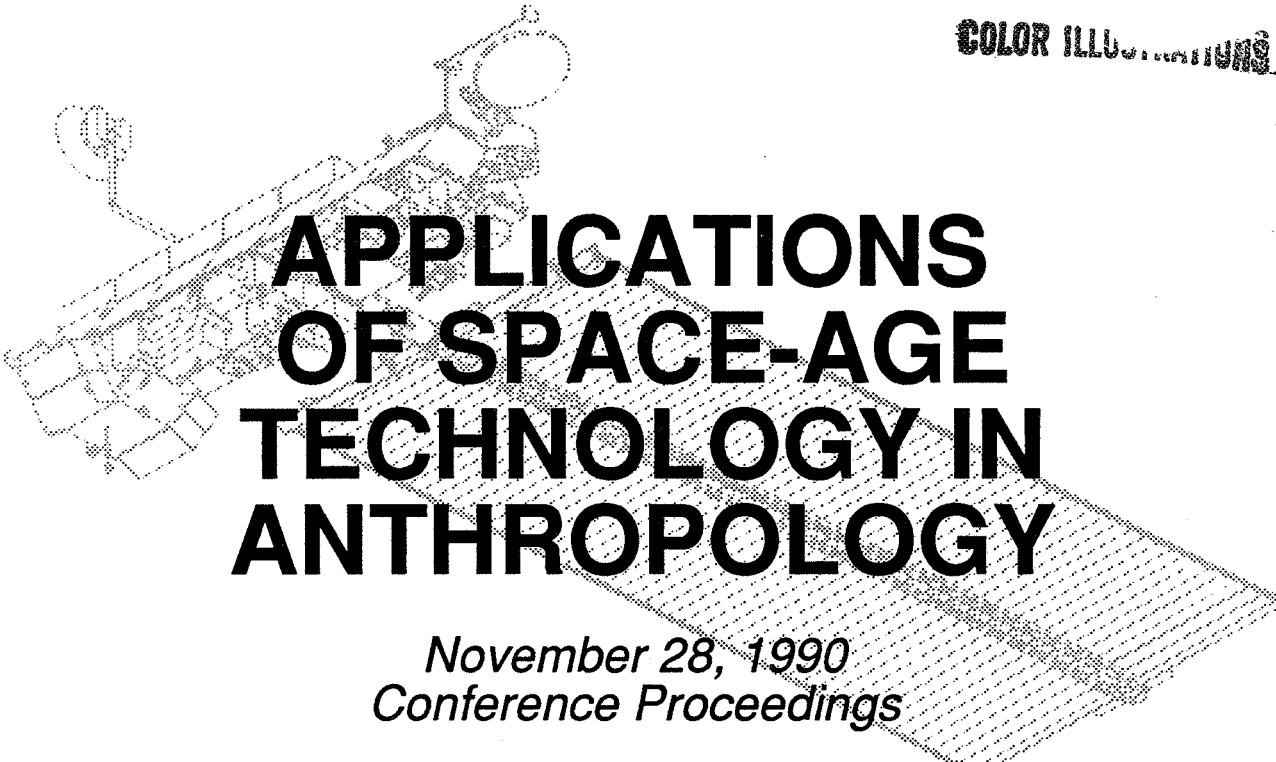


National Aeronautics and
Space Administration

John C. Stennis Space Center



ORIGINAL CONTENTS
COLOR ILLUSTRATIONS



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

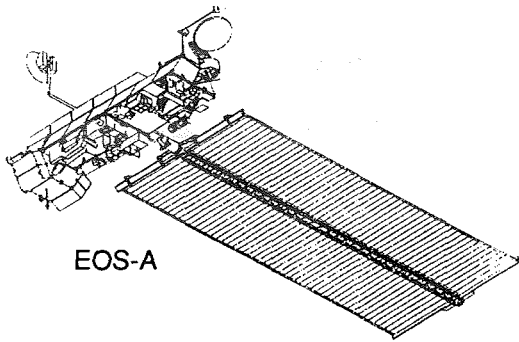
*November 28, 1990
Conference Proceedings*

**Organized by
Clifford A. Behrens
and Thomas L. Sever**

**NASA
Science and Technology Laboratory
John C. Stennis Space Center, Mississippi**

May 1, 1991

Second Edition



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

About the Cover


EOS-A:

The first Earth Observing System (EOS-A) has been conceived and designed to provide observations from a low-altitude Earth orbit. The observations will provide a characterization of the state of the whole planet and detailed measurement of its regional variations. The EOS information system capability will build up over 10 years, then function for at least a decade at its full capacity. EOS data will provide an improved predictive model of the integrated Earth system and a better understanding of human interactions. Without an understanding of human behavior and its consequences for the environment, models will be inadequate to explain, or to develop policies to deal with, global change phenomena.

Photograph:

Ngutcha assists in obtaining the precise location of the Nepoko river bridge in Zaire using a backpack, battery powered, GPS receiver. GPS locations like this were used by Dr. David Wilkie, to create the first Landsat Thematic map of the Ituri rain forest, allowing World Wildlife Fund to avoid human settlements when delineating the boundaries of the new Okapi National Park. Landsat maps like this are vital in minimizing conflicts between biodiversity conservation and indigenous peoples' rights (See article "Protecting Rain Forests and Forager's Rights Using Landsat Imagery", pp.181-193).





APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

Preface

CONTENTS

Preface	1
Conference Agenda	3
Conference Participants	5
Papers	
Applications of Satellite Image Processing to the Analysis of Amazonian Cultural Ecology (Clifford A. Behrens)	9-1
GIS, GPS, Political History and Geo-Demography of the Aramamisis Yanomamo Expansion (Napoleon A. Chagnon)	35-2
Satellite Spectral Data and Archaeological Reconnaissance in Western Greece (F.A. Cooper, M.E. Bauer, and B.C. Cullen)	63-3
Use of Ground-Penetrating Radar Techniques in Archaeological Investigations (James A. Doolittle and W. Frank Miller)	81-4
GIS Modeling of Archaeological Site Locations: A Low-Tech Approach (Eugene M. Futato)	95-5
Settlement Patterns, GIS, Remote Sensing and the Late Prehistory of the Black Prairie in East Central Mississippi (Jay K. Johnson)	111-6
Applications of Ecological Concepts and Remote Sensing Technologies in Archaeological Site Reconnaissance (W. Frank Miller, Thomas L. Sever, and Daniel Lee)	121-7
New Technology and Regional Studies in Human Ecology: A Papua New Guinea Example (George E.B. Morren, Jr.)	137-8
"Very-to-Barely" Remote Sensing of Prehistoric Features under Tephra in Central America (Payson D. Sheets)	167-9
Protecting Rain Forests and Forager's Rights Using Landsat Imagery (David S. Wilkie)	181-10
Preliminary GIS Analysis of the Agricultural Landscape of Cuyo Cuyo, Department of Puno, Peru (Bruce Winterhalder and Tom Evans)	195-11
Applications of a Hand-Held GPS Receiver in South American Rain Forests (Michael Baksh)	227-12

Continuous Cost Movement Models (W. Fredrick Limp)

237-13

Traditional Anthropology and Geographical Information Systems in the
Collaborative Study of Cassava in Africa (Steven Romanoff)

251-14

Discussions

Comments on the NASA-Sponsored Session on Remote Sensing at Stennis Space
Center, Nov. 28, 1990 (Emilio F. Moran)

261

Discussion (James Wiseman)

267

PREFACE

The papers in this volume were presented at a conference entitled, "Applications of Space-Age Technology in Anthropology," held on November 28, 1990, at NASA's Science and Technology Laboratory (STL), part of the John C. Stennis Space Center, Mississippi. The conference was sponsored by NASA and consisted of formal paper presentations, open discussions, and demonstrations of hardware and software.

Over the last couple of decades, a number of conferences and workshops have convened to better inform anthropologists about new space-age technologies. In 1975 a research workshop, "Satellite Potentials for Anthropological Studies of Subsistence Activities and Population Change," was held in Washington, D.C. This seminal meeting was organized by Francis Conant and Priscilla Reining with support from the National Science Foundation and the American Association for the Advancement of Science. Another conference, "Remote Sensing and Archaeology: Potential for the Future," followed in 1984 and was organized by Thomas Sever and James Wiseman. This meeting was held at NASA's Earth Resources Laboratory (now STL) and received funding from NASA, NSF, and the National Geographic Society. A third conference, "Cultural and Ecological Applications of Remote Sensing," met at the University of Colorado-Boulder in 1987. This meeting was organized by Paul Shankman, Daniel Gross, and Thomas Sever, and was supported by NSF and NASA. At the moment there exists the mistaken impression that few, if any, productive results ever developed from these meetings. To the contrary, some anthropologists have successfully applied new technologies to their research, and others are eager to do so, as demonstrated by the papers in this publication.

One reason for this conference was to facilitate information exchange among a diverse group of anthropologists. Much of the research in anthropology that has made use of satellite image processing, geographical information systems, and global positioning systems has been known to only a small group of practitioners or "true believers." This conference represents the first concerted attempt to bring together archaeologists and social-cultural anthropologists, experienced and inexperienced alike, to examine the enormous potential of these technologies. It was anticipated that more experienced users of these technologies could share essential information so anthropologists new to the field might also learn to apply them. There is a real need to open lines of communication among anthropologists so that new information about these technologies and their uses in anthropology is more quickly disseminated. This conference took an important step toward achieving this objective.

A second reason for this conference was to promote scientific dialogue between anthropologists and professionals outside of anthropology. It is certain that both the development and proper application of new technologies will only result from greater cooperation between technicians and "end-users." We all know that, in these times of budgetary constraints, much technical development (e.g., hardware and software) is application driven. It certainly seems that anthropologists, with their concern for human adaptation, environmental and cultural resource management, and protection of indigenous people, can provide many useful applications to justify the costs of new technological development. Moreover, given the severe and difficult field conditions in which many anthropolo-

gists work, they should be able to push the capabilities of new devices and help field test them as they become available. As a means for improving communications between professionals with interests in anthropological applications of new technologies, we have included a list of conference participants in these proceedings.


This conference was made possible through the efforts of many people. We would like to thank Dr. Shelby Tilford, Director of NASA's Earth Science and Applications Division, for his vision in supporting our pioneering research efforts over the last few years. As a result, the discipline of Anthropology has made great advances in incorporating remote sensing/GIS technology into its scientific research designs. Furthermore, we now feel that our discipline can make major contributions to global change research, especially in the area of Human Interactions.

We would like to thank Gerald Smith, Deputy Director of the Stennis Space Center, and Myron Webb, Public Affairs Officer, for their efforts in hosting this conference. We would like to recognize Harry Hoff and Daniel Lee, Lockheed Engineering and Sciences Company, for their instruction and data analysis support throughout the last few years. We would also like to thank Frederick Mayer, Charlotte Timmons, and Debbie Diecidue for making conference arrangements and overseeing publication of these proceedings. We also wish to acknowledge Richard Sellers, Boyce Clark, and Dianne Edrington for their support in demonstration preparations and logistical arrangements. And to all other NASA employees and staff who contributed to this conference or publication of these proceedings we extend our sincere gratitude.

Finally, we dedicate this publication to Paul Shankman who has been an important catalyst to these proceedings and who continues to inspire us professionally and personally.

Clifford A. Behrens
Thomas L. Sever

March 1, 1991



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

Conference Agenda

APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

NASA Science and Technology Laboratory
Stennis Space Center
November 28, 1990

Conference Agenda

8:45 Welcome and Introduction

Papers and Discussion: Part I

9:00 Doolittle and Miller
9:20 Miller, Sever and Lee
9:40 Sheets
10:00 Johnson

10:20 Break

10:30 Cullen
10:50 Morren
11:10 Behrens
11:30 Discussion

11:45 Lunch

Papers and Discussion: Part II

1:00 Baksh (Read by Behrens)
1:20 Chagnon
1:40 Wilkie
2:00 Limp (Read by Lee)
2:20 Winterhalder


2:30 Break

3:10 Discussant: Dr. Emilio Moran
3:30 Discussant: Dr. James Wiseman
3:50 Discussion

4:30 Data Sources: Mr. Hank Svehlak, USGS
GRASS Demonstration: Mr. Daniel Lee, Lockheed
GPS Demonstration: Mr. Frank Miller, MSU
Mr. Richard Sellers, Lockheed

5:30 Return to New Orleans

Page intentionally left blank



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

Conference Participants

APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

NASA-STL, Stennis Space Center
November 28, 1990

Drs. Clifford Behrens and Thomas Sever, Organizers

Conference Participants

Mr. Larry Banks
Division of Archaeology
Army Corp of Engineers
1114 Commerce St.
Dallas, Texas 75242

Dr. Timothy Baugh
Department of Archaeology
675 Commonwealth Ave., Rm 675
Boston University
Boston, MA 02215
(617) 353-9678
tim@bucrsc.bu.edu

Dr. Clifford A. Behrens
Latin American Center
10-343 Bunche Hall
University of California
Los Angeles, CA 90024
(213) 825-4571
XBEHREN@UCLASSCF

Dr. Napoleon Chagnon
Department of Anthropology
University of California
Santa Barbara, CA 93106
(805) 893-2257

Mr. Boyce Clark
762 Lorraine St.
Jackson, MS 39202
(601) 352-8744

Dr. Francis Conant
Department of Anthropology
Hunter College, CUNY
695 Park Avenue
New York, NY 10021

Dr. Frederick Cooper
Classics 310 Folwell Hall
9 Pleasant St. SE
University of Minnesota
Minneapolis, MN 55455
(612) 625-5353

Ms. Brenda Cullen
Classics 310 Folwell Hall
9 Pleasant St. SE
University of Minnesota
Minneapolis, MN 55455

Mr. James Doolittle
US Dept. of Agriculture
Soil Conservation Service
160 E. Seventh St.
Chester, Pennsylvania 19013
(215) 499-3960

Dr. Jack D. Elliott, Jr.
Mississippi Dept. of Archives & History
c/o Cobb Institute of Archaeology
Drawer AR
Mississippi State, MS 39762

Dr. Ben Finney
Department of Anthropology
University of Hawaii
2424 Maileway
Honolulu, Hawaii 96822
(808) 956-2855

Mr. Eugene Futato
Office of Archaeological Research
1 Mound State Monument
Moundville, AL 35474

Dr. Jon L. Gibson
Department of Anthropology/Sociology
University of Southwestern Louisiana
Box 40198
Lafayette, LA 70504
(318) 231-6045

Barbara E. Grandin
Department of Human Ecology
Cook College, Rutgers University
P.O. Box 231
New Brunswick, NJ 08903

Mr. Glen Green
Department of Geology
Macalester College
1600 Grand Ave.
St. Paul, MN 55105
(612) 696-6183

Mr. Harry Hoff
Lockheed Engineering & Sciences Co.
Building 1210
Stennis Space Center
SSC, MS 39529
(601) 688-1954

Dr. Ed Jackson
Dept. of Sociology/Anthropology
Box 5074 Southern Station
University of Southern Mississippi
Hattiesburg, MS 39406

Dr. Allen Johnson, Chair
Department of Anthropology
University of California, Los Angeles
Los Angeles, CA 90024
RAJHNSN@UCLASSCF

Dr. Jay Johnson
Department of Sociology and Anthropology
University of Mississippi
University, MS 38677
(601) 232-7339

Mr. Gurcharan Khanna
Department of Anthropology
University of California, Berkeley
Berkeley, CA 94720

Mr. C. Dan Lee
Lockheed Engineering & Sciences Co.
Building 1210
Stennis Space Center
SSC, MS 39529
(601) 688-2464

Mr. Frederick J. Mayer
Lockheed Engineering & Sciences Co.
Building 1210
Stennis Space Center
SSC, MS 39529
(601) 688-3775

Mr. Frank Miller
PO Drawer FR
Mississippi State, MS 39762

Dr. Emilio F. Moran
Department of Anthropology
Indiana University
Bloomington, IN 47405
(812) 855-5821

Dr. George E. B. Morren
Department of Anthropology
Rutgers University
New Brunswick, NJ 08903
(201) 932-9627

Dr. Robert Murowchick
Peabody Museum
Harvard University
Cambridge, MA 02138

Dr. Stuart Plattner
Program Director for Social/
Cultural Anthropology
National Science Foundation
Washington, D.C. 20550

Mr. Conrad Reining
Conservation International
1015 18th Street, Suite 1000
Washington, D.C. 20036

Dr. Priscilla Reining
3601 Rittens House St. NW
Washington, D.C. 20036

Mr. Jon Schneeberger
National Geographic Society
17th & M St. NW
Washington, DC 20036

Mr. Richard Sellers
Lockheed Engineering & Sciences Co.
Building 1210
Stennis Space Center
SSC, MS 39539
(601) 688-1969

Dr. Thomas Sever
NASA Science & Technology
Laboratory
Stennis Space Center
SSC, MS 39529

Dr. Paul Shankman
Department of Anthropology CB 233
University of Colorado
Boulder, CO 80309-0233

Dr. Payson Sheets
Department of Anthropology
University of Colorado
Boulder, CO 80309-0233
(303) 492-6003


Mr. Hank Svehlak
USGS/NMD
Earth Science Information
Center
Building 3101
SSC, MS 39529

Dr. David Wilkie
645 Centre St.
Newton, MA 02158
MORELLIG@BCVMS
(617) 527-1662

Dr. Bruce Winterhalder
Department of Anthropology
University of North Carolina
Chapel Hill, NC 27514
(919) 962-1662
BPW12@UNC

Dr. James Wiseman
Institute for Advanced Study
Olden Lane, West Building 216
Princeton, NJ 08540
(609) 734-8356

Page intentionally left blank



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

Papers

APPLICATIONS OF SATELLITE IMAGE PROCESSING TO THE ANALYSIS OF AMAZONIAN CULTURAL ECOLOGY

Clifford A. Behrens*

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

ABSTRACT

51-45
201788
p. 22

This paper examines the application of satellite image processing towards identifying and comparing resource exploitation among indigenous Amazonian peoples. The use of statistical and heuristic procedures for developing land cover/land use classifications from Thematic Mapper satellite imagery will be discussed along with actual results from studies of relatively small (100-200 people) settlements. Preliminary research indicates that analysis of satellite imagery holds great potential for measuring agricultural intensification, comparing rates of tropical deforestation, and detecting changes in resource utilization patterns over time.

Key Words: cultural ecology, remote sensing, satellite image analysis, Geographical Information System, Amazon

INTRODUCTION

This paper reports results from a study to determine the feasibility of using satellite imagery to measure variables important for cultural ecological research. An analysis is made of Thematic Mapper imagery from eastern Peru to identify land cover and land use patterns among the Shipibo, an indigenous Amazonian group who have begun to produce dry rice for sale in regional markets.

The process of agricultural intensification in Amazonia has long occupied the concern of cultural ecologists. Now this concern has been heightened by the environmental crisis associated with rapid tropical deforestation. Recent research has focused on indigenous systems of resource management and the manner in which local tropical forest ecosystems are disrupted by more intensive land use practices such as cash cropping and cattle ranching (Buschbacher 1986; Hect 1981, 1983; Moran 1981, 1983; Posey and Balee 1987; Schmink and Wood 1985; Schumann and Partridge 1989; also see McKay and Acheson 1987). The need to measure land use patterns at a regional level, and to rapidly detect changes in these patterns, requires newer approaches to collecting and processing data than those previously available in the cultural ecologist's toolkit. While environmental scientists and some archaeologists have successfully applied remote sensing techniques to address similar problems, little use has been made of satellite imagery by cultural ecologists other than mere visual inspection of imagery much like aerial photography has been used in the past.

In this paper, the spatial and radiometric resolution of Thematic Mapper imagery is evaluated for cultural ecological analysis along with the potential of computer-assisted numerical and graphical techniques. This will be followed by recommendations for future data acquisition and tools that better meet the analytical needs of cultural ecologists who study small-scale agriculturalists in tropical forest ecosystems.

*Latin American Center, University of California, Los Angeles.

MEASUREMENT IN CULTURAL ECOLOGY

The measurement of environmental variables important for cultural ecological analysis is often difficult and very time consuming. It is almost impossible for a single researcher to collect land use data on the ground, let alone on a regional scale. Researchers in other disciplines have successfully applied remote sensed data to solve their problems of measurement and scale, and so it seems reasonable that these methods might also assist cultural ecologists. However, to determine the potential of these new technologies for research on small-scale agriculturalists, the adequacy of spatial and spectral resolution provided by current platforms still requires closer examination.

Measurement of Key Variables

Concepts such as agricultural intensification, population pressure, ecological zonation, and territorial circumscription have been important among cultural ecologists for explaining social-cultural variability in the Amazon (Chagnon 1973; Gross 1983; Johnson and Earle 1987; Meggers 1954; Vasey 1979). Some have attempted to quantify these concepts with estimates of Amazonian natives' carrying capacity, time allocation, garden sizes and composition, and the location of faunal resource procurement sites (Behrens 1986, 1989a; Carneiro 1961; Hames and Vickers 1983; Johnson 1976). However, measuring the precise geographical location of settlements and resource procurement sites in poorly mapped regions is a recurring problem in the Amazon. Moreover, the mapping of gardens and their composition among shifting agriculturalists, who do not cultivate on a regular basis, is extremely labor intensive. (In fact, it is often difficult to determine where a forest ends and a garden begins!) Travel to gardens during both the extreme dry and wet seasons can be slow and difficult, further impeding data collection. Estimation of garden yields using only simple sampling methods in the field is a crude procedure, at best. Nor is it practical to measure the amount of land in gardens or left to fallow, and rates of deforestation and other habitat destruction by different agricultural systems on the ground.

In addition, some cultural ecologists have argued for a need to collect these land use and resource procurement data on a regional level (e.g. Gross 1984; Moran 1984). Thus, there seems a desire for detailed environmental data capable of distinguishing microhabitats, but on a large geographical scale. Researchers in other disciplines have already applied remote sensing technologies towards addressing both these problems of precision and scale.

Remote Sensing Approach

The analysis of remote digital images has become an indispensable tool to natural resource managers and environmental planners (Estes and Senger 1974; Lillesand and Kiefer 1987; Lindgren 1985; Lintz and Simonnet 1976). The feasibility of applying remote sensing technology to mapping and managing tropical forest resources has been demonstrated in numerous studies (Baltaxe 1980; Danjoy and Sadowski 1978; Eden and Parry 1986; Giddings et al. 1980; Green 1983; Sader et al. 1990a; Singh 1984a). Examples of remote sensing research projects throughout Latin America now exist (for surveys, see Hoffer and Bartolucci 1980; Wagner and Bartolucci 1980), particularly in inaccessible regions of the Amazon forest where the technology has proven to be extremely useful for mapping vegetation and soils (Danjoy 1977, 1984; Shimabukuro et al. 1984; Sieffermen 1980).

One of the greatest potentials for satellite imagery recognized early by researchers was the

determination of crop distributions and yields (e.g. Bauer 1975). Within the last decade, some have used remote sensing methods to monitor shifting cultivation and land use patterns among indigenous populations in Africa and Asia (Adeniyi 1986; Bruneau and LeToan 1978; Miller et al. 1978; Mushala 1986; Roy et al. 1985; Singh 1984b). In the Amazon, LANDSAT images have been analyzed to survey shifting cultivation in southwest Guyana (Eden 1986), and to determine the commercial potential of palm trees and rates of deforestation in the jungle of Peru (Danjoy 1977, 1984).

Within anthropology, archaeologists seem to have been quickest to incorporate remotely sensed data in their work (e.g. Deuel 1969; Ebert 1984; Lyons and Avery 1977; Lyons and Mathien 1980; Sever and Wiseman 1985; Sheets 1987; Wilson 1975, 1982). Despite earlier interest in the application of aerial photography to anthropological field research (Vogt 1974), little use has been made of satellite imagery by ecologically-oriented cultural anthropologists. Three exceptional projects include a study of shifting cultivation in east Africa (Conant 1984; Conant and Cary 1977), research on desertification, carrying capacity, and human settlement in west Africa (Reining 1979), and a study of land use patterns among the Mbuti in the Ituri forest of northeastern Zaire (Wilkie and Finn 1988). Other projects were proposed at a recent conference on cultural and ecological applications of remote sensing (Shankman et al. 1987).

These previous applications of satellite image processing suggest that new technologies might assist cultural ecologists at measuring land use patterns and detecting changes in these patterns over time. But there has been little attempt to evaluate the efficacy of these techniques among small-scale agriculturalists in the Amazon who occupy small (<200 people) settlements and whose garden sizes are typically less than a single hectare (cf. Beckerman 1987). The land cover in the vicinity of Amazonian settlements also tends to vary greatly, with lush forests, gardens consisting of different crops, and fallow land in various stages of succession. Thus, two questions of concern to cultural ecologists are (1) Is the spatial resolution of current satellite imagery adequate enough to distinguish gardens typical of small-scale agriculturalists? and (2) Is the radiometric resolution sufficient for detecting fairly subtle, but important, variations in levels of radiation reflected by different land cover/land use classes of interest to cultural ecologists?

EXPERIMENTAL STUDY AREA

The questions above will be examined using data collected within the ethnographic territory of the Shipibo, a Panoan-speaking group (Loukotka 1968; Shell and Wise 1971) of shifting agriculturalists who inhabit the Central Ucayali River of eastern Peru and its major western tributaries (see Figure 1). Presently, the Shipibo (and closely related Conibo) population includes more than 16,000 members (Chirif and Mora 1976; Uriarte 1976).

Physical Environment

The study area falls within the limits of Moist Tropical Forest (Tosi 1960). This is the most extensive vegetative zone in Peru and includes approximately 484,655 km² or one-third of Peru. In its virgin state the forest consists of dense evergreens dominated by large dicotyledonous trees approximately 40-50 m tall and varying from 90-400 cm in diameter. A few of the large trees found in the area include caoba (*Weietenia* spp.), catahua (*Hura crepitans*), caucho (*Castilloa elastica*), cedro (*Cedrella odorata*), lupuna (*Chorisia insignis*), moena (*Endlicheria anomala*), quinilla (*Manilkara bidentata*), shiringa (*Hevea brasiliensis*), and topa (*Ochroma lagopus*) (Soukup 1970; Tosi 1960; UNESCO 1978; Villarejo 1979).

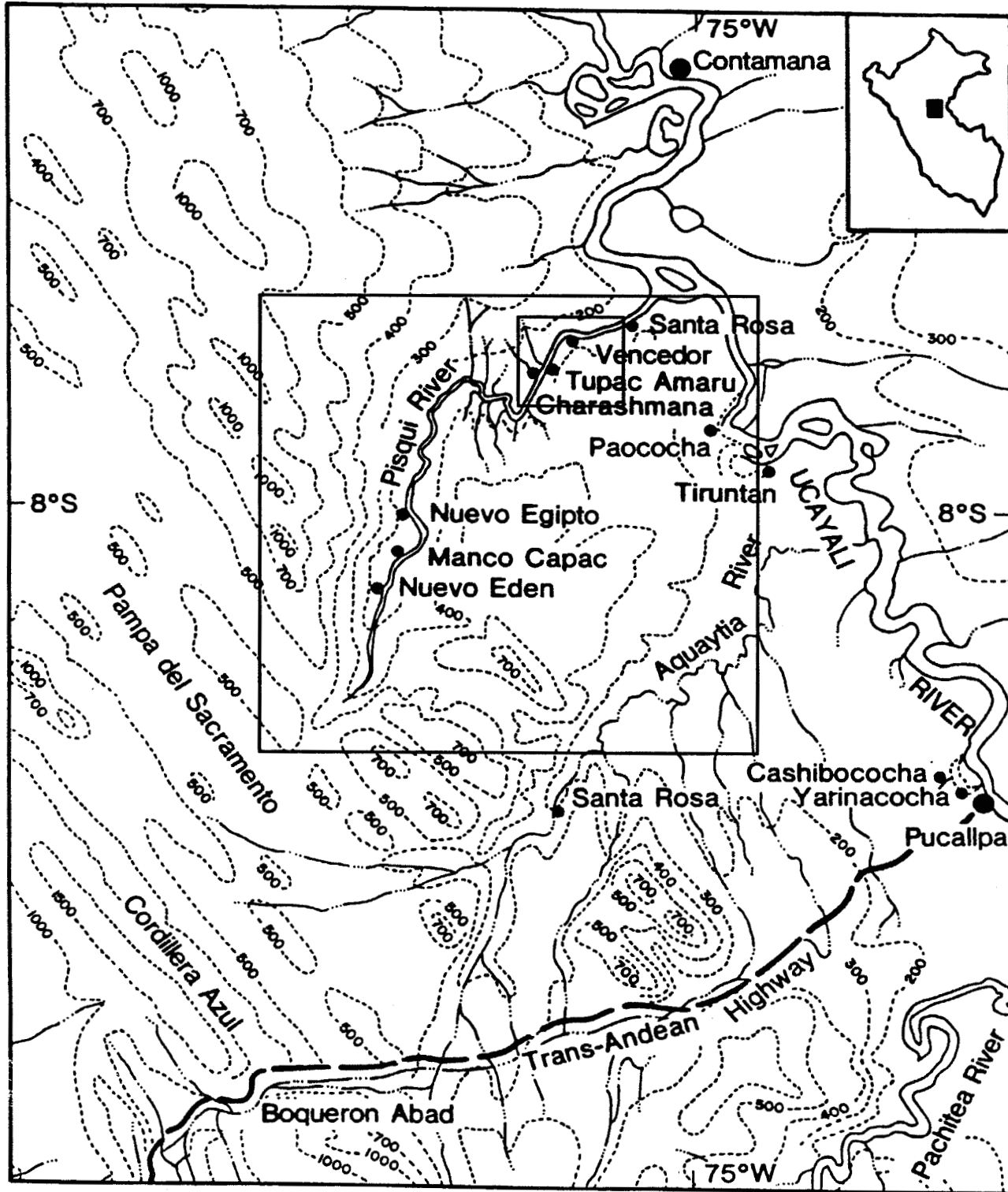


Figure 1. Pisqui Region, TM Subscene, and Lower Pisqui Study Area.

The physical environment within the Pisqui River region is diverse and transitional between the Cordillera Azul (part of the Andes) in the west and the Ucayali River Basin in the east (Bergman 1980; Campos 1977). Steeper river beds and greater topographical relief in the Upper Pisqui distinguish this area from that of the Lower Pisqui and Ucayali zones. The geomorphology of the Upper Pisqui is less diverse with much narrower *playas* (point bars), smaller *restingas* (natural levees), and *tahuampas* (backswamps) which are sparser, smaller, and shallower. The upper region of the Pisqui also lacks many large *cochas* (oxbow lakes) typical of the Ucayali landscape, but one finds numerous *quebradas* (smaller rivers or streams) which are tributaries of the Pisqui and part of the vast dendritic drainage system of the Peruvian Montaña (Drewes and Drewes 1957; Tosi 1960; Villarejo 1970). Strictly speaking, Shipibo who live in the Pisqui region inhabit neither a *varzea* nor a *terra firme* habitat, but occupy an intermediate habitat that shares geomorphological features of both environments.

Land Use Patterns

The Pisqui River region is also characterized by significant ethnic and agricultural variability. On the Pisqui there exist Shipibo and *mestizo* communities with small-scale agricultural systems that vary in their intensity of land use, crops grown, and soils used. Shipibo communities near the mouth of the Pisqui have access to better developed beaches and levees, that are seasonally replenished with nutrient-rich alluvia deposited after flooding, and so they follow agricultural practices more similar to those described for Ucayali ribereño communities (c.f. Bergman 1980). Thus, there is greater variability in the soils used to support agriculture near the mouth, ranging from silty to clayey, acid to basic, and flood-free to seasonally inundated. However, in the headwaters where the drainage pattern is more dendritic, flooding occurs over shorter periods, largely due to runoff from the mountains after heavy rainfall, and so agricultural zonation is less heterogeneous.

The level of market participation also differs among communities on the Pisqui River. Crop inventories of ribereño farmers on the Amazon suggest that more cash crops are often grown by *mestizos*, particularly cereals, legumes, and vegetables, than by Shipibo farmers (Hiraoka 1985). The latter tend to cultivate primarily *Musa* (plantains and bananas) and manioc (*Manihot esculenta*) for subsistence, and some grow rice to sell (Behrens 1986, 1989a). For example, informants from the *mestizo* community of Nuevo Egipto report that they produce a greater variety of crops and sell more rice to markets in Contamana than Shipibo communities in the same vicinity such as Manco Capac. Analyses of time allocation and food consumption data indicate that, indeed, Shipibo rice producers are expending more time in agricultural work during shorter periods than before (Behrens 1989b). The need to recruit labor during rice planting and harvesting is tending to concentrate more people and gardens nearer villages with the consequence of depleting local forest and faunal resources.

Thus, within the Pisqui River region one finds increasingly intensive uses of agricultural land in *mestizo* communities and near the mouth of the Pisqui in communities that are closer to regional marketplaces. In the next section of this paper, satellite imagery will be analyzed to determine which land cover/land use classes in the Lower Pisqui area can be detected and to estimate the size of each class.

ANALYSIS

To evaluate the feasibility of applying remote sensing techniques to the analysis of small-scale

agriculture in the study area a preliminary land use/land cover classification was made for the Lower Pisqui. Again, particular attention is focussed on assessing the adequacy of spatial and radiometric resolution in existing satellite imagery.

Image Acquisition

Remote sensing is the science and art of gathering information about an object, area, or phenomenon from a distance through instruments that are sensitive to various bands of the electromagnetic spectrum (cf. Lillesand and Kiefer 1987). While the human eye only detects a minute portion of this spectrum (.4 to .77 micrometers), mechanical scanners are able to sense objects with greater resolution and more precise bandwidths. Moreover, the use of satellites equipped with remote sensing devices has made it possible to detect features on the earth not possible with black-and-white or color-infrared aerial photography.

In 1972 the United States launched the first satellite in, what came to be known as, its LANDSAT project. Since that time, five LANDSAT satellites have been sensing and recording information about the earth. LANDSAT satellites 4 and 5, launched in 1982 and 1984 respectively, use an advanced scanner called a "Thematic Mapper" (or "TM") to collect data on seven different bands of the electromagnetic spectrum. Since different ground features possess distinct reflective properties, analysis of the spectral data detected by the Thematic Mapper satellites can be used to identify these features from distant space. The radiometric resolution of the TM sensor is described in Table 1.

Table 1. Thematic Mapper spectral bands and their applications (Source: Lillesand and Kiefer 1987).

Band	Wavelength (μm)	Nominal Spectral Location	Principal Applications
1	0.45-0.52	Blue	Coastal water mapping, soil/vegetation discrimination, forest type mapping, cultural feature identification.
2	0.52-0.60	Green	Vegetation discrimination, cultural feature identification.
3	0.63-0.69	Red	Chlorophyll absorption for species differentiation, cultural feature identification.
4	0.76-0.90	Near-infrared	Biomass surveys, vegetation types, water body identification, soil moisture discrimination.
5	1.55-1.75	Mid-infrared	Vegetation moisture content and soil moisture.
6	10.4-12.5	Thermal infrared	Vegetation stress analysis, soil moisture discrimination, and thermal mapping.
7	2.08-2.35	Mid-infrared	Mineral and rock discrimination, and measuring vegetation moisture content.

For example, data sensed on bands 1-3 are particularly useful for detecting cultural features on the earth's surface, such as buildings and roads; whereas bands 5 and 7 have been used to discriminate among rock types. LANDSATs 4 and 5 have a sun-synchronous, near-polar orbit cycle of 16 days and pass over the earth at an altitude of 705 km. Each LANDSAT scene has a scale of 1:1,000,000, covers an area of 34,000 km², and images gathered by the Thematic Mapper have a spatial resolution of 30 meters.

LANDSAT images can be purchased by the public. However, the availability of images for any particular area can only be determined through extensive searches of computerized data bases, once the appropriate satellite path and row for the study area have been identified. Furthermore, once this information is determined, images may be found to be of little use because they were not collected at the right time or are obscured by cloud cover. The latter is a persistent problem for those who require imagery from tropical regions of the world like the Amazon Basin.

A search was made of EOSAT data bases to determine the existence of satellite imagery for the Pisqui area. Two sets of LANDSAT images with sufficient quality were identified and one of these sets was purchased by NASA's Science and Technology Laboratory (STL) and used for this feasibility study. A 100 km by 100 km subscene, with its upper left corner at 7°32.925'S 75°48.9'W, was constructed by merging parts of two LANDSAT Thematic Mapper scenes (Y5099714281X0 and Y5098714284X0) taken on November 13, 1986. A false color composite (described below) of this subscene was generated (Figure 2).

To simplify analysis and minimize computer time, a 512 x 512 pixel image, representing an area of approximately 15 km x 15 km, was extracted for the Lower Pisqui using ELAS, NASA's Earth Resources Laboratory Applications Software (NASA 1987). The area enclosed by the entire Pisqui subscene, along with the Lower Pisqui area used for preliminary classification, is delineated in figure 1.

Image Classification

Image classification applies quantitative procedures to automatically identify features in a scene (Jensen 1986; Lillesand and Kiefer 1987). Two general types of spectrally oriented procedures are frequently used to derive land cover classes for mapping. Supervised classification makes use of numerical descriptors of various land cover types in a scene already known by the analyst, either through experience or from ground truth data collected in the field. Representative sites with known cover types are sampled and these data, called "training sets," are used to build an interpretation key. With this key, the computer assigns a cover type to individual pixel values. In an unsupervised classification digital image data are aggregated statistically into natural spectral groupings or clusters. Then, the analyst determines the land cover identity of each cluster by comparing the classified image data to ground reference data.

The data resolution and amount of variability contained in the original TM data for the Lower Pisqui area were examined by creating a "false color" composite image (Figure 3). Through this procedure the red, blue, and green color guns in the graphics display are assigned to the three TM bands. For this false color image, the blue gun was assigned to band 1, the red gun to band 5, and the green gun to band 4. (The data for bands 2 and 3 showed striping, distortion caused by a malfunction in one of the sensors, and so were not usable; nor was band 6 used because of its different

ground resolution.) The resulting color of any pixel in the graphic is determined by "mixing" gun colors based on the intensity values for that pixel on each of the three bands. The graphic has been enlarged so that 4 pixels are used to represent each pixel in the original TM data. One can readily identify such features as the river and oxbow lakes, forest, old river channels and marshy areas, and what appear to be occupation zones along the river, including recent man-made clearings (the rectangular groupings of red pixels).

Obviously, one would like a more parsimonious description of land cover and land use patterns represented in the image. For example, pixels in heavily forested areas are colored black, brown, tan, and numerous shades of green. This variability in the data could be caused by different levels of radiation reflected by distinct species of trees, shadow effects, or any number of other factors of little or no interest to this study. For purposes of this analysis one would prefer to group in a single class those pixels that tend to covary on several of the TM bands. To classify the image for the Lower Pisqui, cluster analysis and maximum likelihood classification modules contained in the ELAS library were applied to bands 1, 4, 5, and 7 of the TM data.

One difficulty in conducting a maximum likelihood cluster analysis is determining a priori the maximum number of clusters for the software to extract from the data. To resolve this issue, a land cover/land use classification based on a taxonomy published by the USGS (cf. Anderson et al. 1976) was proposed for the study area. This taxonomy contains three levels of detail closely related to the ground resolution of different observational platforms. From inspection of Table 2 it is learned that level II classes correspond with the spatial resolution provided by TM imagery.

In this study, those classes not applicable to the Peruvian Amazon, e.g. Tundra, were obviously not even considered as cluster candidates. Thus, an attempt was made to consider as potential classes only those in the classification for which enough information existed (through personal experience) to actually distinguish these classes in the cluster analysis results. With these criteria in mind, 17 clusters was input as the maximum limit for statistical analysis. Those classes used to arrive at this number are marked in Table 3 with an asterisk.

The cluster analysis produced 16 classes for the Lower Pisqui subscene, shown in Figure 4. In this image, one immediately notices that less colors are used. In fact there are only 16 different colors of pixels, one color for each class. Some classes in this image are readily interpretable. For example, blue pixels are obviously water (the river and lakes), and red pixels indicate heavily forested areas. Other classes are enigmatic. For example, yellow pixels seem to be located in areas subject to periodic flooding (meander spurs and old river channels), and green pixels bordering the river seem

Table 2. Spatial Resolution for Each Level in the USGS Land Cover/Land Use

Classification (after Anderson et al. 1976).

LC/LU Classification Level	Representative Image Format
I	Landsat MSS
II	Small scale aerial photos, Landsat TM and SPOT images (< 1:80,000 scale)
III	Medium scale aerial photos (1:20,000 - 1:80,000 scale)
IV	Large scale aerial photos (> 1:20,000 scale)

ORIGINAL PAGE
COLOR PHOTOGRAPH

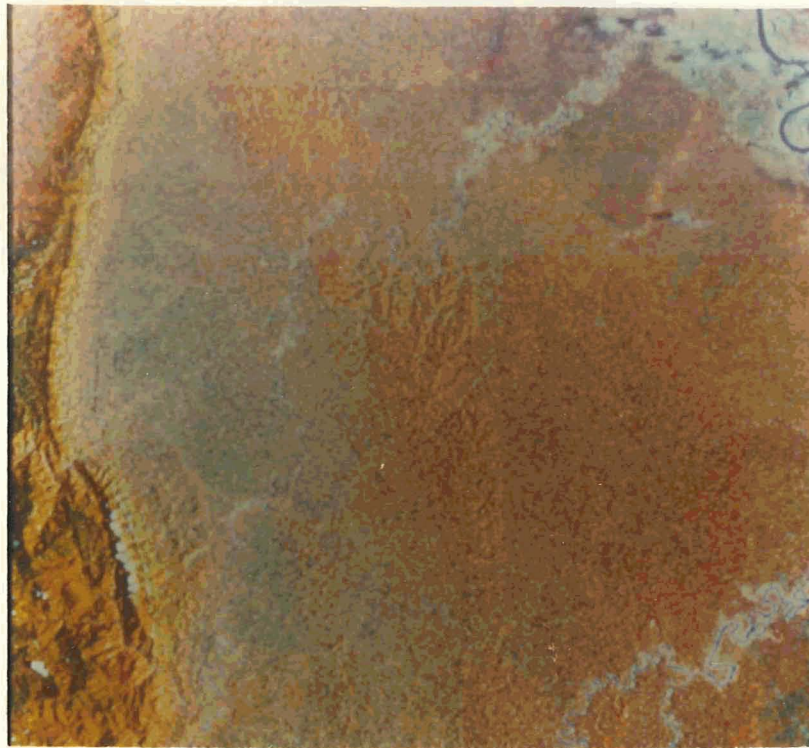


Figure 2. False Color Composite of 100 km x 100 km TM Subscene.



Figure 3. False Color Composite of Lower Pisqui study area.

Table 3. Proposed Land Cover and Land Use Classification for the Lower Pisqui River Region of Eastern Peru (after Anderson et al. 1976).

Level I	Level II	Level III
1 Urban or Built-up Land	11 Residential	111* Single-family Units
	14 Transportation, Communications, and Utilities	112 Multi-family Units
		141* Streets
		142 Roads and Trails
2 Agricultural Land	21 Cropland and Pasture	211* Cropland
		212* Idle Cropland
		213* Pasture
	24 Other Agricultural Land	241 Farmsteads
		242* Holding Areas for Livestock
3 Rangeland	(Not Applicable)	
4 Forest Land	41* Deciduous Forest	
	42* Evergreen Forest (Tropical Hardwoods)	
	43* Mixed Forest	
5 Water	51* Streams and Canals	
	52* Lakes	
6 Wetland	61 Forested Wetland (Natural, not Cultivated)	611* Marshes
		612 Mudflats
	62* Nonforested Wetland	613* Swamps
7 Barren Land	72* Beaches	
	73 Sandy Areas other than Beaches	
	74* Bare Exposed Rock	
	76 Transitional Areas	761* Forest Land Cleared for Agriculture
8 Tundra	(Not Applicable)	
9 Perennial Snow or Ice	(Not Applicable)	

to mark zones of human impact.

An improvement in the interpretation of statistically generated classes was made in two ways. First, all of the pixels for each class were highlighted (turned white) to determine where they were located in the image. This technique (called "sliding colors") produced the following tentative groupings of classes and interpretations: Cropland (classes 4, 6, 10, 11, 15), Pasture (class 14), Forest Land (classes 1, 3, 5, 7, 9, 13), Water (class 8), Wetland (classes 2 and 12), and Barren Land (class 16). A second technique for validating the interpretation above plotted class centroids within the space created by combinations of TM bands, presented in Figure 5. The 3-D graph shows the location of class means within the space formed by the intersection of TM bands 1, 4, and 5. With this plot, some of the more enigmatic classes can be interpreted through their association with better known classes with which they cluster. In addition, because each TM band actually detects different levels of water absorption and biomass in objects on the ground, the location of classes in the graph informs one about physical and biological properties shared by classes within each cluster. In this plot, there is a pronounced vegetative gradient that extends from the Barren Land class, at one extreme, to the Forest Land class at the other with the remaining classes (excluding Water) located in between them. This gradient was particularly useful because it suggested a reasonable interpretation for the Pasture class.

With the additional information gained by sliding colors through classes and by plotting class centroids, there exists a sounder basis for grouping the statistically generated classes into more meaningful land cover/land use superclasses. In addition, a more discriminating color palette has been created to better display these superclasses in the image (see Figure 6). The repainted Lower Pisqui image now shows categories more consistent with the classification proposed above.

Verification

To evaluate the level of detail contained in the classified image a portion of Figure 5 including the villages of Charashmana and Tupac Amaru, and representing an area of approximately 6 km x 6 km, was blown-up (see Figure 7). In this image, 25 pixels represent one pixel in the TM data. Most Shipibo settlements follow a traditional linear pattern with thatched-roofed houses (approximately 7m by 4m) built along an unpaved street, opposite cooking structures, and roughly parallel to the river. In fact, both villages appear in the image as rows of white pixels that run parallel to the river. Charashmana, on the left bank of the Pisqui contains approximately 200 people and (with an average of about 7 people per household) 25-30 houses (cf. Behrens 1989b; Hern 1988). Tupac Amaru, located on the right bank just downriver from Charashmana, has a population of about 100 people and, therefore, 10-15 houses.

The detail revealed in this blow-up also suggests that it should be possible to distinguish at least three classes of Barren Land, specifically Villages, Newly Cleared Gardens (the white areas inside the red zones), and Sandy Beaches (the white pixels found on the tip of meander spurs of the river). It is also possible to examine clusters for additional groups using the WCCL (Within Cluster Classification) module contained in ELAS. In addition, other sparsely vegetated areas near each village, possibly soccer fields or pastures, seem to appear as rectangles of yellow pixels in Figure 6. This finding provides encouragement for the possibility that some of the classes of Cropland detected by the satellite, and also revealed statistically, may represent fallow land or even gardens planted in different crops, e.g., *Musa*, manioc, or rice.

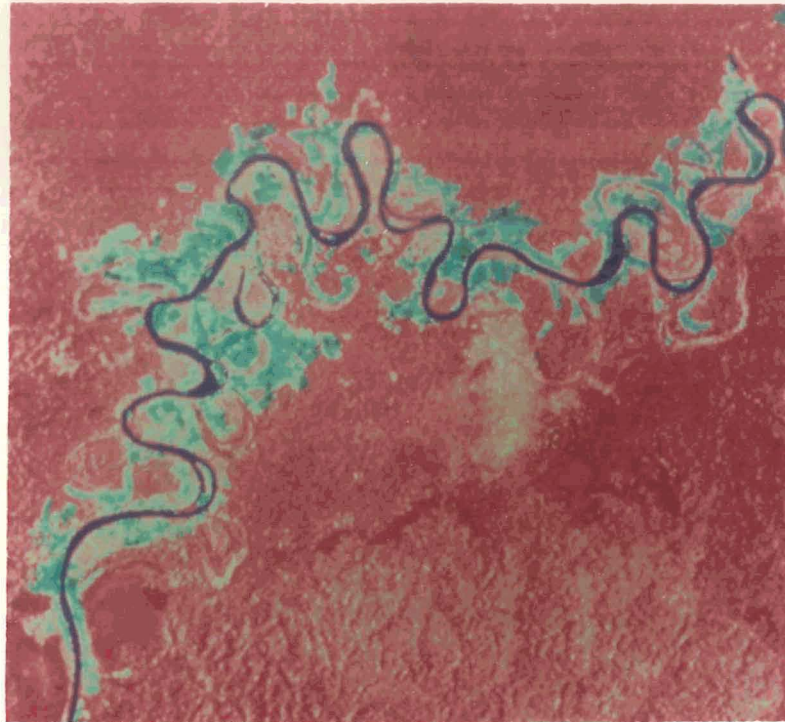


Figure 4. Classification of Lower Pisqui Study area.

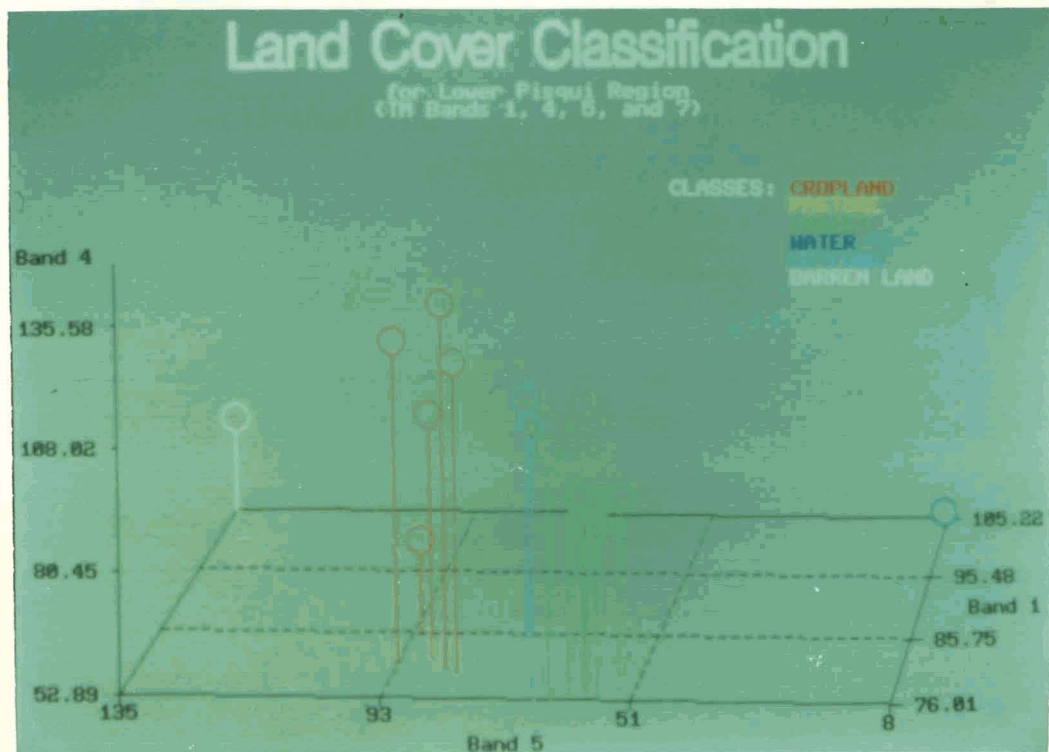


Figure 5. Three-Dimensional Plot of Class Centroids.

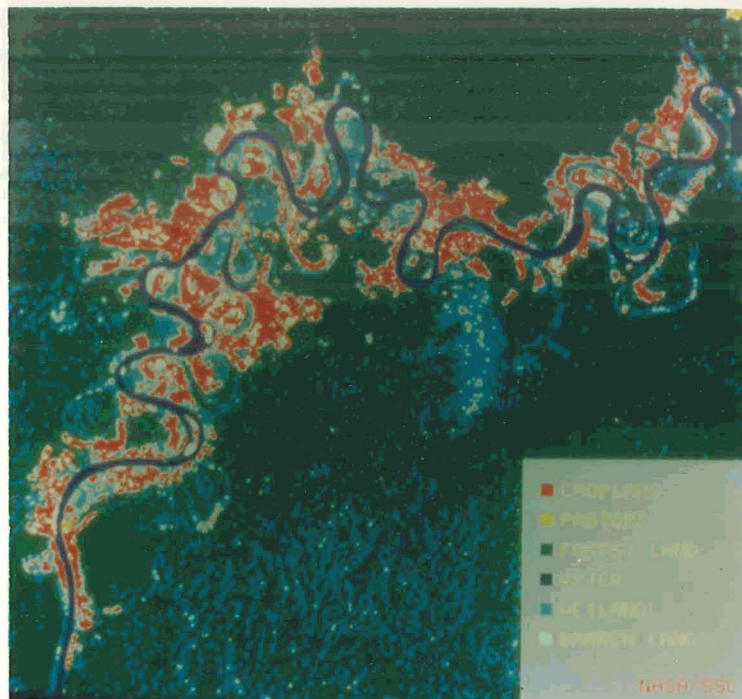


Figure 6. Land Cover/Land Use Superclasses for Lower Pisqui Study Area

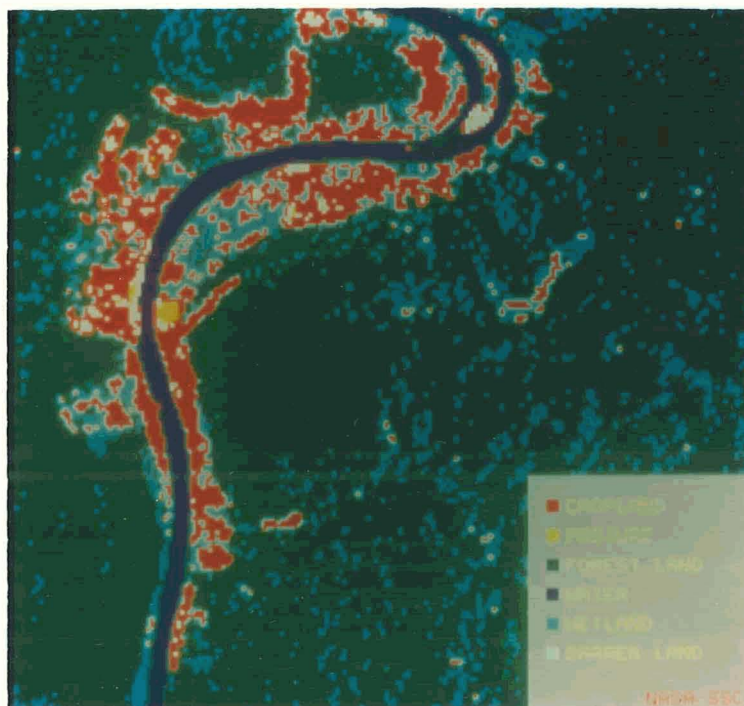


Figure 7. Blow-up of Lower Pisqui study area in the Vicinity of the Shipibo Villages of Charashmana and Tupac Amaru.

FUTURE WORK

The analysis above represents only a preliminary effort to interpret land cover and use in the study area. A more precise interpretation is obtained with a supervised classification. Once an image has been accurately classified, it is possible to compare it with other images, or relate features that have been discriminated in an image either to each other or to other kinds of data. This is the purpose of a geographic information system (or GIS).

Supervised Classification

Unsupervised classification provides knowledge of the approximate number of distinct land cover/land use classes represented in the TM imagery, and their geographical locations. Nevertheless, it is desirable to collect ground truth data to validate classes. A more precise identification of the five classes of Cropland in the Lower Pisqui image awaits the collection of ground truth data in the field. With a Global Positioning Receiver one can obtain accurate locational data (to within 25 meters) for each land cover/land use class discovered in the unsupervised classification (Wilkie 1989, 1990). Then these data provide a more accurate range of pixel values for known classes. Using the ground truth data as a training set, it will be possible to conduct a supervised classification of the study area so as to improve upon the land cover/land use classification presented here (Jensen 1986; Lillesand and Kiefer 1987).

GIS Analysis of Classified Image

A GIS is designed to store, manipulate, and display location and descriptive data about features in a map (Burrough 1986; Jensen 1986; Lillesand and Kiefer 1987). By decomposing the information in a map into its constituent data "layers," a GIS can be used to analyze the relationships between different layers. With the power of a GIS, a researcher can merge data from different sources to form a single map, converting maps to a common scale in the process. This "georeferenced" data base can then be analyzed statistically to calculate class areas just by counting the number of grid cells with certain properties and multiplying this by the area of each cell.

For example, using the results from image classifications as source data to a GIS, a researcher can estimate the amount of primary forest, fallow gardens, and active gardens in an area (Nellis et al. 1990). It is already known that each TM pixel represents a 30m x 30m area on the ground. Therefore, one only has to multiply the number of pixels for a land cover/land use class by 900 m² to calculate the class' total area. As an experiment, the classified Lower Pisqui image was imported into GRASS (Geographical Resources Analysis and Support System), the GIS selected for this study (USACE 1988). Once converted to a cell map, it was possible to estimate coverage and percent of total subscene area for each of the six land cover/land use superclasses. These figures are reported in Table 4.

Using GRASS to manage the image produced by a supervised classification, it is also possible to obtain estimates of areas for each class and, therefore, the amount of cropland per capita for each village along with ratios of active garden area to fallow garden area (a more precise measure of the intensity of agricultural land use). Furthermore, it should be possible to calculate rates of deforestation (Grainger 1983, 1984; Nelson and Holben 1986; Singh 1986) and evaluate the potential for small-scale agricultural systems in interfluvial areas of the Amazon to sustain sedentary human

populations as they increase their market participation (cf. Alvim 1980; Carneiro 1961; Gross 1983; Meggers 1954; also Ryerson et al. 1985).

CONCLUSIONS

This feasibility study has demonstrated that the spatial and radiometric resolution of Thematic Mapper imagery seems adequate for cultural ecological analysis of small-scale agriculture in tropical forest ecosystems. Remote sensing techniques can provide accurate estimates of key environmental variables in a cost effective manner, and on the regional scale desired by many Amazonian researchers. Furthermore, with accurate ground truth data obtained with a GPS, it should be possible to determine exact geographical locations for sites of interest, such as villages, gardens (possibly with different crops), fallow land, pasture, and fishing and hunting grounds. Using a GIS such as GRASS, one can accurately estimate land cover/land use class areas, as well as calculate distances between villages and gardens and other resource utilization zones, a next to impossible task in the field. These data, in turn, can provide the training set for supervised classification so as to refine land cover/land use classes derived from preliminary analyses of satellite imagery.

While satellite imagery can solve many of a cultural ecologist's data collection problems, there still exist some limitations for those who require imagery from areas in the Amazon (cf. Sader et al. 1990b). Landsat and SPOT images for many parts of the Amazon are few and most are rendered useless by cloud cover. For this reason, there is growing need for imagery collected by active sensors such as microwave devices. While the spectral coverage provided by TM imagery is better, the 20 m ground resolution in multispectral SPOT imagery is an advantage over TM data for those who study small-scale agriculture. It is the desire of this researcher that future space platforms carry radar systems and pointable multispectral sensors with at least 20 m ground resolution. These improvements will provide cultural ecologists with the detailed, timely data they need to classify and compare indigenous land use patterns at a regional level, and to detect changes in these patterns as they occur.

ACKNOWLEDGMENTS

This research was supported by National Science Foundation research grants BNS 88-12823 and BNS 89-11090. I wish to thank Thomas Sever (NASA's Science and Technology Laboratory, Stennis Space Center) and Richard Sellers, Don Powell and Fred Mayer (Lockheed Engineering and Sciences, Stennis Space Center) for their generous assistance in procuring and processing the satellite imagery used for this study.

Table 4. Estimated Areas for Each Land Cover/Land Use Category in the Lower

Pisqui Subscene.

Category	Hectares	% of Total Area
Cropland	1,871	7.93
Pasture	26	.11
Forest Land	18,068	76.58
Water	739	3.13
Wetland	2,664	11.29
Barren Land	225	.95
Total	23,593	100

REFERENCES

- Adeniyi, P. O. 1986. Agricultural land use inventory and mapping in Nigeria: the application of remote sensing. In Eden, M. J., and J. T. Parry (eds.), *Remote Sensing and Tropical Land Management*. London: John Wiley and Sons.
- Alvim, P. T. 1980. Agricultural production potential of the Amazon region. In F. Barbira-Scazzocchio (ed.), *Land, People and Planning in Contemporary Amazonia*. Cambridge: Center for Latin American Studies.
- Anderson, J. R., et al. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, USGS Professional Paper 964. Washington, D. C.: U.S. Government Printing Office.
- Baltaxe, R. 1980. The Application of LANDSAT Data to Tropical Forest Surveys. Rome: Food and Agriculture Organization (FAO).
- Bauer, M. E. 1975. The role of remote sensing in determining the distribution and yield of crops. *Advances in Agronomy* 27: 271-304.
- Beckerman, S. 1987. Swidden in Amazonia and the Amazon Rim. In B. L. Turner and S. B. Brush (eds.), *Comparative Farming Systems*. New York: The Guilford Press.
- Behrens, C. A. 1986. The cultural ecology of dietary change accompanying changing activity patterns among the Shipibo. *Human Ecology* 14: 367-396.
- Behrens, C. A. 1989a. The scientific basis for Shipibo soil classification and land use: changes in soil-plant associations with cash cropping. *American Anthropologist* 91(1): 83-100.
- Behrens, C. A. 1989b. Shipibo Time Allocation. *Cross-Cultural Studies in Time Allocation*, Volume 4. New Haven: Human Relations Area Files.
- Bergman, R. W. 1980. *Amazon Economics: The Simplicity of Shipibo Indian Wealth*. Syracuse, NY: Dellplain Latin American Studies.
- Bruneau, M., and T. LeToan. 1978. An interpretation of northern Thailand's widening and multiple cropping systems using multitemporal LANDSAT images and computer compatible tapes. *Proceedings of the 12th International Symposium on Remote Sensing of the Environment*, Environmental Research Institute of Michigan, Ann Arbor Michigan, pp. 1883-1889.
- Burrough, P. A. 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Monographs on Soil and Resources Survey, No. 12. Oxford: Clarendon Press.
- Buschbacher, R. J. 1986. Tropical deforestation and pasture development. *Bioscience* 36: 22-28.
- Campos, R. 1977. Producción de pesca y caza de una aldea Shipibo en el Río Pisqui. *Amazonia Peruana* 1: 53-74.

- Carneiro, R. L. 1961. Slash-and-burn cultivation among the Kuikuru and its implications for cultural development in the Amazon Basin. *Anthropologica Supplements* 2: 47-67.
- Chagnon, N. 1973. The cultural-ecology of shifting (pioneering) cultivation among the Yanomamo Indians. In D. Gross (ed.), *Peoples and Cultures of Native South America*. New York: Natural History Press.
- Chirif, A., and Mora, C. 1976. *Atlas de Comunidades Nativas*. Lima, Peru: Sistema Nacional de Apoya a la Movilización Social, Dirección General de Organizaciones Rurales.
- Conant, F. P. 1984. Remote sensing, discovery, and generalizations in human ecology. In E. Moran (ed.), *The Ecosystem Concept in Anthropology*. Boulder, CO: Westview Press.
- Conant, F. P., and T. K. Cary. 1977. A first interpretation of east African swiddening via computer assisted analysis of 3 LANDSAT tapes. *Proceedings of the Machine Processing of Remotely Sensed Data Symposium*, Purdue University Laboratory for Applications of Remote Sensing, West Lafayette, Indiana.
- Danjoy, W. A. 1977. *Use of Remote Sensing Systems: Evaluating the Potential of the Aguaje Palm Tree in the Peruvian Jungle*, Final Report. Lima: Oficina Nacional de Evaluación de Recursos Naturales (ONERN).
- Danjoy, W. A. 1984. Uses of remote sensing for monitoring and control of deforestation in the high jungle of Peru. *Proceedings of the 18th International Symposium on Remote Sensing of the Environment*, Environmental Research Institute of Michigan, Ann Arbor Michigan, p. 1031.
- Danjoy, W. A., and F. Sadowski. 1978. Use of LANDSAT in the study of forest classification in the tropical jungle. *Proceedings of the 12th International Symposium on Remote Sensing of the Environment*, Environmental Research Institute of Michigan, Ann Arbor Michigan, pp. 947-955.
- Deuel, L. 1969. *Flights into Yesterday - The Story of Aerial Archaeology*. New York: St. Martin's Press.
- Drewes, Wolfram Y., and Arlene T. Drewes. 1957. *Climate and Related Phenomena of the Eastern Andean Slopes of Central Peru*. Syracuse: Syracuse University Research Institute.
- Ebert, J. I. 1984. Remote sensing application in archaeology. *Advances in Archaeological Method and Theory*, Vol 7. New York: Academic Press.
- Eden, M. J. 1986. Monitoring indigenous shifting cultivation in forest areas of Southwest Guyana using aerial photography and Landsat. In Eden, M. J., and J. T. Parry (eds.), *Remote Sensing and Tropical Land Management*. London: John Wiley and Sons.
- Eden, M. J., and J. T. Parry (eds.). 1986. *Remote Sensing and Tropical Land Management*. London: John Wiley and Sons.
- Estes, J. E., and L. W. Senger. 1974. *Remote Sensing - Techniques for Environmental Analysis*. Santa Barbara, CA: Hamilton.

- Giddings, L. E., et al. 1980. The use of LANDSAT data in mapping tropical vegetation. *Proceedings of the 14th International Symposium on Remote Sensing of Environment*, Environmental Research Institute of Michigan, Ann Arbor, pp. 1383-1387.
- Grainger, A. 1983. Improving the monitoring of deforestation in the humid tropics. In S. L. Sutton, T. C. Whitmore, and A. C. Chadwick (eds.), *Tropical Rain Forest: Ecology and Management*. Oxford: Blackwell Scientific Publications.
- Grainger, A. 1984. Quantifying changes in forest cover in the humid tropics: overcoming current limitations. *Journal of World Forest Resources Management* 1: 3-63.
- Green, K. M. 1983. Using LANDSAT to monitor tropical forest ecosystems: realistic expectations of digital processing technology. In Sutton, S. L., T. C. Whitmore, and A. C. Chadwick (eds.), *Tropical Rain Forest: Ecology and Management*. Oxford: Blackwell Scientific Publications.
- Gross, D. 1983. Village movement in relation to resources in Amazonia. In R. Hames and W. Vickers (eds.), *Adaptive Responses of Native Amazonians*. New York: Academic Press.
- Gross, D. 1984. Ecosystems and methodological problems in ecological anthropology. In E. Moran (ed.), *The Ecosystem Concept in Anthropology*. Boulder, CO: Westview Press.
- Hames, R., and W. Vickers (eds.). 1983. *Adaptive Responses of Native Amazonians*. New York: Academic Press.
- Hecht, S. B. 1981. Deforestation in the Amazon Basin: magnitude, dynamics and soil resource effects. *Studies in Third World Societies* 13: 61-108.
- Hecht, S. B. 1983. Cattle ranching in the Amazon: environmental and social implications. In E. Moran (ed.), *The Dilemma of Amazonian Development*. Boulder, CO: Westview Press.
- Hern, Warren. 1988. Polygyny and Fertility among the Shipibo: An Epidemiologic Test of an Ethnographic Hypothesis. Unpublished Doctoral Dissertation, Department of Epidemiology, University of North Carolina, Chapel Hill, NC.
- Hiraoka, M. 1985. Floodplain farming in the Peruvian Amazon. *Geographical Review of Japan* 58: 1-23.
- Hoffer, R. M., and L. A. Bartolucci. 1980. Mapping land cover in Latin American countries by computer-aided analysis of satellite scanner data. *Proceedings of the 14th International Symposium on Remote Sensing of the Environment*, Environmental Research Institute of Michigan, Ann Arbor Michigan, pp. 415-425.
- Jensen, J. R. 1986. *Introductory Digital Image Processing: A Remote Sensing Perspective*. Englewood Cliffs, NJ: Prentice-Hall.
- Johnson, A. 1976. Time allocation in a Machiguenga community. *Ethnology* 14: 301-310.
- Johnson, A., and T. K. Earle. 1987. *The Evolution of Human Societies: From Foraging Group to Agrarian State*. Stanford, CA: Stanford University Press.

- Lillesand, T. M., and R. W. Kiefer. 1987. *Remote Sensing and Image Interpretation*, Second Edition. New York: Wiley.
- Lindgren, D. T. 1985. *Land Use Planning and Remote Sensing*. Dordrecht: Nijhoff.
- Lintz, J., and D. S. Simonnet (eds.). 1976. *Remote Sensing of Environment*. Reading, MA: Addison-Wesley.
- Loukotka, C. 1968. *Classification of South American Indian Languages*, J. Wilbert (ed.). Los Angeles: UCLA Latin American Center.
- Lyons, T. R., and T. E. Avery. 1977. *Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers*. Washington, D.C.: National Park Service.
- Lyons, T.R., and F.J. Mathien (eds.). 1980. *Cultural Resources Remote Sensing*. Washington, D.C.: Cultural Resources Management Division, National Park Service.
- McKay, Bonnie J., and James M. Acheson. 1987. *The Question of the Commons: The Culture and Ecology of Communal Resources*. Tucson: University of Arizona Press.
- Meggers, B. J. 1954. Environmental limitations on the development of culture. *American Anthropologist* 56: 801-824.
- Miller, L. D., K. Nualchawee, and Tom C. 1978. Analysis of the dynamics of shifting cultivation in the tropical forest of northern Thailand using landscape modelling and classification of LANDSAT imagery. *Proceedings of the 12th International Symposium on Remote Sensing of the Environment*, Environmental Research Institute of Michigan, Ann Arbor Michigan, pp. 1167-1185.
- Moran, E. F. 1981. *Developing the Amazon*. Bloomington, Indiana: Indiana University Press.
- Moran, E. G. 1983. Growth without development: past and present development efforts in Amazonia. In E. Moran (ed.), *The Dilemma of Amazonian Development*. Boulder, CO: Westview Press.
- Moran, E. G. 1984. The problem of analytical level shifting in Amazonian ecosystems research. In E. Moran (ed.), *The Ecosystem Concept in Anthropology*. Boulder, CO: Westview Press.
- Mushala, H. M. 1986. Multistage Remote Sensing, Land Systems, and Soil erosion in Central Tanzania. In Eden, M. J., and J. T. Parry (eds.), *Remote Sensing and Tropical Land Management*. London: John Wiley and Sons.
- NASA. 1987. *ELAS: Earth Resources Laboratory Applications Software, Volume II, User Reference*. National Space Technology Laboratories, Earth Resources Laboratory: National Aeronautics and Space Administration.
- Nellis, M. Duane, Kamlesh Lulla, and John Jensen. 1990. Interfacing geographic information systems and remote sensing for rural land-use analysis. *Photogrammetric Engineering and Remote Sensing* 56: 329-331.

- Nelson, R., and B. Holben. 1986. Identifying deforestation in Brazil using multiresolution satellite data. *International Journal of Remote Sensing* 7: 429-448.
- Posey, D. A., and W. Balee (eds.). 1987. *Indigenous Land Use of Amazonian Peoples*. New York: New York Botanical Garden.
- Reining, P. 1979. *Challenging Desertification in West Africa: Insights from LANDSAT into Carrying Capacity, Cultivation, and Settlement Sites in Upper Volta and Niger*. Athens: Center for International Studies, Ohio University.
- Roy, P., R. Kaul, R. Sharma Roy, M., and S. Garbyal. 1985. Forest-type stratification and delineation of shifting cultivation areas in the eastern part of Arunchai Pradesh using LANDSAT MSS data. *International Journal of Remote Sensing* 6: 411-418.
- Ryerson, R. A., R. N. Dobbins, and C. Thibault. 1985. Timely crop area estimates from Landsat. *Photogrammetric Engineering and Remote Sensing* 51: 1735-1743.
- Sader, Steven A., and Thomas A. Stone (eds.). 1990a. Remote Sensing for Monitoring Tropical Moist Forests: Special Issue. *Photogrammetric Engineering and Remote Sensing* 56.
- Sader, Steven A., Thomas A. Stone, and Armond T. Joyce. 1990b. Remote sensing of tropical forests: an overview of research and applications using non-photographic sensors. *Photogrammetric Engineering and Remote Sensing* 56: 1343-1351.
- Schmink, M., and C. H. Wood (eds.). 1985. *Frontier Expansion in Amazonia*. Gainesville: University of Florida Press.
- Schumann, Debra A., and Wil'iam L. Partridge (eds.). 1989. *The Human Ecology of Tropical Land Settlement in Latin America*. Boulder, CO: Westview Press.
- Sever, T., and J. Wiseman. 1985. Remote Sensing and Archaeology: Potential for the Future. Report on a Conference held March 1-2, 1984 at the NASA National Space Technology Laboratories' Earth Resources Laboratory. (Contains bibliography.)
- Shankman, P., T. Sever, and D. Gross. 1987. *Cultural and Ecological Applications of Remote Sensing: Final Report*. Conference sponsored by NSF/NASA, Department of Anthropology, University of Colorado, Boulder, April 23-25, 1987.
- Sheets, P. D. 1987. Geophysical Exploration for Ancient Maya Housing at Cerén, El Salvador. *Remote Sensing Newsletter in Anthropology and Archaeology* 1(2): 4-7.
- Shell, O. A., and M. R. Wise. 1971. *Grupos Idiomáticos del Perú, Segunda Edición*. Lima: Universidad Nacional Mayor de San Marcos/Instituto Lingüístico de Verano.
- Shimabukuro, Y., J. Dos Santos, and L. De Aquino. 1984. Vegetation survey in Amazonia using LANDSAT data. *Proceedings of the 16th International Symposium on Remote Sensing of Environment*, Environmental Research Institute of Michigan, Ann Arbor, pp. 797-799.

Siefferman, G. 1980. Contribution to soil mapping of southern Venezuela using computer analysis of LANDSAT II data. Proceedings of the 14th International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, p. 1221.

Singh, A. 1984a. Discrimination of tropical forest cover types using LANDSAT MSS data. Symposium on Machine Processing of Remotely Sensed Data, pp. 395-403.

Singh, A. 1984b. Detecting changes in tropical forest cover due to shifting cultivation using LANDSAT MSS data. Proceedings of the 10th Anniversary Conference on Satellite Remote Sensing, Remote Sensing Society, Reading, United Kingdom.

Singh, A. 1986. Change detection in the tropical forest environment of Northeastern India using LANDSAT. In Eden, M. J., and J. T. Parry (eds.), Remote Sensing and Tropical Land Management. London: John Wiley and Sons.

Soukup, Jaroslav S. B. 1970. Vocabulario de los Nombres Vulgares de la Flora Peruana. Lima: Colegio Salesiano.

Tosi, Joseph A., Jr. 1960. Zonas de Vida Natural en el Perú: Memoria Explicativa sobre el Map Ecológico del Perú. Proyecto 39, Programa de Cooperación Técnica, Boletín Técnico No. 5. Lima, Peru: Instituto Interamericano de Ciencias Agrícolas de la O.E.A., Zona Andina.

UNESCO/UNEP/FAO. 1978. Tropical Forest Ecosystems: A State of Knowledge Report. Paris: UNESCO.

U. S. Army Corps of Engineers. 1988. GRASS 3.0. Champaign, IL: Construction Engineering Research Laboratory (CERL).

Uriarte, L. M. 1976. Poblaciones nativas de la Amazonía Peruana. Amazonia Peruana 1: 9-58.

Vasey, Daniel E. 1979. Population and agricultural intensity in the humid tropics. Human Ecology 7(3): 269-283.

Villarejo, A. 1979. Así es la Selva. Iquitos: Publicaciones CETA (Centro de Estudios Teologicos de la Amazonía).

Vogt, E. Z. (ed.). 1974. Aerial Photography in Anthropological Field Research. Cambridge: Harvard University Press.

Wagner, T., and L. A. Bartolucci. 1980. Remote sensing applications in Latin America and the Caribbean. Proceedings of the 14th International Symposium on Remote Sensing of the Environment, Environmental Research Institute of Michigan, Ann Arbor Michigan, pp. 27-31.

Wilkie, David S. 1989. Performance of a backpack GPS in a tropical rainforest. Photogrammetric Engineering and Remote Sensing 55: 1747-49.

Wilkie, David S. 1990. GPS location data: an aid to satellite image analyses of poorly mapped

regions. Technical Note. *International Journal of Remote Sensing* 11: 653-58.

Wilkie, David S., and J. T. Finn. 1988. A spatial model of land use and forest regeneration in the Ituri forest of northeastern Zaire. *Ecological Modelling* 41: 307-323.

Wilson, D.R. (ed.). 1975. *Aerial Reconnaissance for Archaeology*, Research Report no. 12. London: Council for British Archaeology.

Wilson, D.R. 1982. *Air Photo Interpretation for Archaeologists*. New York: St. Martin's Press.

**"GIS, GPS, POLITICAL HISTORY AND GEO-DEMOGRAPHY
OF THE ARAMAMISI YANOMAMÖ EXPANSION"**

Napoleon A. Chagnon^{*1}

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

52-45
201789
p. 26

ABSTRACT

This year a joint US-Venezuelan research project was initiated to locate, identify, and begin long term research on the ecology of the Siapa Basin and the cultural adaptations of Yanomamö communities to this habit, a poorly mapped region of southern Venezuela. During two separate field trips, representing over 500 hours of flying time, local informants were asked to guide a helicopter to villages and other areas of anthropological interest. The location of each place was established with a GPS instrument. Both the Trimble Navigation TransPak and Magellan Nav 1000 Pro were used on these trips. A brief summary of the results and preliminary comparisons of both instruments will be presented.

INTRODUCTION

Synopsis of the Research Problem

I am currently initiating a 10-year study of the Yanomamö Indians of southern Venezuela and northern Brazil, research that will eventually include the study of other native Venezuelan groups in this general area. During the Summer and Fall of 1990 several events took place that will not only revolutionize my anthropological research in the future, but are likely to resolve a number of theoretical problems in cultural anthropology that my previous work has played a major role in creating.

First, I was able to spend a considerable amount of time flying over areas of the Venezuelan Amazon in helicopters, which enabled me to gain a very different perspective on the geography and ecology of regions that I had previously only visited by canoe and on foot. I had been working in these areas for many years. Second, I purchased a Trimble Navigation TransPack G.P.S. instrument and was able to determine, within approximately 30 meters, the locations of many existing villages, rivers, river mouths, mountains, and abandoned gardens; native informants who flew in some of the helicopter flights identified these features for me.² Finally, I discovered how remotely-sensed data and G.I.S. applications can be used to shed light on some of the problems my 27-years

^{*}Professor of Anthropology University of California Santa Barbara, CA 93106

¹ The field research on which this article is based has been conducted over many years and benefited from many research grants. This support came principally from the National Science Foundation and the Harry Frank Guggenheim Foundation. My 1990 field trip was supported by the Office of Research Development and the Academic Senate of the University of California in collaboration with FUNDAFACI. I am especially grateful to Sras. Milagros Mendoza and Cecilia Matos of FUNDAFACI for their generous support. I thank Darius Chagnon for preparing the Maps in this paper.

of research on the Yanomamö Indians of this area have raised.

One of these problems is as follows. I have been studying a large, multi-village tribe of Amazon Indians, the Yanomamö, who are one of the few tribal groups left on earth whose members continue to conduct inter-village warfare without interference from the nation states (Venezuela and Brazil) within which they reside. My overall findings on the causes and patterns of violence, mortality rates, population densities, infanticide practices, competition for strategic material resources, and individual striving cannot be adequately explained in terms of current anthropological theories of warfare in band and village societies, particularly theories advocated by the "cultural materialist" school (Harris, 1974; 1979; 1984; Ross & Ross, 1980; Gross, 1975). A key dilemma is as follows. First, the Yanomamö have very low population densities, but are engaged in chronic warfare in the areas I have worked. Yet there appears to be an adequacy, if not abundance, of natural resources, including cultivable land for gardens. Second, extensive biomedical evidence suggests they are well nourished and are not suffering from deficiencies in dietary items (Neel, 1977). Third, high rates of population growth suggest that their population is not limited by resources (Chagnon, 1974; Neel & Weiss, 1975; Melancon, 1982); vast areas of under- or unpopulated areas abound. Fourth, all villages are technologically self-sufficient, i.e., can obtain whatever natural materials needed to sustain their technology and economy.³ Finally, the stated Yanomamö reasons for their within-village fighting and inter-village warfare never include shortages of land for gardening or access to hunting areas...or trade goods from the outside world. Basically, they claim that they fight over women, usually within the village but occasionally between villages, and these fights sometimes result in mortalities. The mortalities must be avenged and, in turn, these acts trigger long vendettas motivated by revenge. In addition, some lethal attacks are the result of accusations of sorcery or soul-stealing, but in the area I work, these are less often cited as reasons for initiating hostilities than are histories of earlier conflicts that begin at local levels, frequently over women but also over insults to male status, and escalate to more serious forms and ultimately involve whole villages (Chagnon, 1988).

I will make a claim in this paper that will surely provoke other anthropologists who have worked among other groups of Yanomamö to respond vigorously. I argue that the geographical area I am studying is the source of approximately 25% of all living Yanomamö, both in Venezuela and Brazil—if the total number of Yanomamö is approximately 20,000 people. Therefore, if any area can be said to be the demographic "cradle" of contemporary Yanomamö culture, it is the area I have been working in and will continue to work in during the coming years. This argument can be substantiated or refuted by empirical research of the kind described below, i.e., it is a testable proposition. I invite my colleagues to test it. My projected field studies will, I believe, substantiate this claim. The results of projected field studies, especially census and demographic research, will have an important bearing on issues in which the "representativeness" of the Yanomamö groups I study is questioned by my critics (e.g., Albert, 1989).

² I later also obtained a Magellan Nav 1000 Pro G.P.S. instrument and extended my work in this area and compared position fixes obtained by both instruments for some of the same sites.

³ In more recent times, some villages I have been studying appear to follow settlement patterns that increase their access to Missions where steel tools and other exogenous items are obtained through trade with the native inhabitants who have settled at these Missions...or to seek the 'refuge' of Mission posts to avoid predation by neighboring Yanomamö. This recent pattern can not account for the earlier or the overall pattern of population movements in the regions discussed in this paper or the warfare patterns, which took place at a time when such "contact" points were non-existent.

Overview of the Culture, Geography and Demography

For the past 27 years I have been studying the cultural, demographic, biological, ecological and geographical aspects of the Yanomamö Indians, the largest, relatively unacculturated indigenous population left in the New World (Chagnon, 1983 [1968]; 1974; 1988) and possibly the largest yet-expanding, relatively unacculturated tribe left on earth where native warfare is still a significant fact in the day-to-day political lives of those who yet dwell in the more remote areas. The Yanomamö number approximately 20,000 individuals and are scattered in approximately 250 villages (40 to 300 inhabitants) along the border region between northern Brazil and southern Venezuela, a region that is generally covered with tropical rainforest. Approximately 75% of them live on the Venezuelan side of the border. Not all of their villages have yet been contacted by members of the outside world, particularly in the region to be discussed below. For this reason it is not possible to precisely specify the current number of Yanomamö villages or the total population size with any degree of accuracy.

There is considerable local and regional variation among the Yanomamö in terms of village size, population dynamics, intensity of warfare and other conflicts, language, customs, and degree of contact with outsiders. The region discussed here, the southwestern area of the Yanomamö tribe, is generally characterized by little contact with outsiders, large distances between villages, high levels of inter-personal and inter-group aggression and fighting, high mortality rates due to violence, high incidence of polygyny, high frequencies of abduction of women, high levels of sexual jealousy, powerful motives to seek lethal revenge for previous killings, considerable political authority in the hands of headmen, large villages (150 to 300 people), elaborate alliance patterns involving regular feasting between villages, and very large differences in the variances of reproductive success by males and females (Chagnon, 1988; 1983 [1968]; 1990a; 1974). As will be discussed below, there is significant variation in some of these cultural and ecological variables even within the southwestern region: these constitute the focus of projected studies using GPS and GIS approaches.

I suspect that the overall pattern for the southwestern Yanomamö also occurs in most other areas of the tribe, but in somewhat reduced intensities for most of the variables just mentioned.⁴

Of the several important cultural and biogeographical aspects of the southwestern Yanomamö population, two in particular stand out and are central to the theme of this paper. First, their population is undergoing a high rate of population growth (Chagnon, 1968a & b; 1974; Neel & Chagnon, 1968; Neel & Weiss, 1974; Melancon, 1982; cf Early & Peters, 1990) and, as a consequence, their villages regularly fission into two (occasionally more) groups; one of them moves into an adjacent area and establishes itself as a new political entity, often engaging in hostilities with the very group from which it fissioned. This population 'explosion' is relatable to the post-Columbian introduction

⁴ Colleagues who have worked in those areas tend to focus more on symbolic, linguistic, ceremonial, or other aspects of Yanomamö culture that do not lend themselves easily to quantification, and have generally not provided empirical evidence that would make metric comparisons easy or even possible for most of these variables. A few researchers who work in those areas seem to disbelieve the ethnographic reports I have published on the groups discussed in this paper, especially my descriptions of the degree to which violent conflict dominates Yanomamö social and political life in the area discussed here (Sponsel, 1983; Lizot, 1989; Albert, 1989; 1990; cf. Chagnon, 1990a).

of plantains (*Musa paradisiaca*) and steel tools (axes and machetes) used in clearing gardens (Chagnon, 1966; 1983[1968]). Second, the dynamics of their population growth and dispersal clearly involves a complex set of variables that include both ecological/geographical factors and political factors (Chagnon, 1966; 1968b). That is, the decisions made by village leaders to fission from their current population, move, and establish a new village and garden at a considerable distance appear to be based on considerations of costs and benefits that are both ecological and social in provenience. Thus, members of an expanding group not only appear to consider the geographical and ecological dimensions of it's potential new location—the ability to cross large rivers without watercraft, elevation, ease of travel to hunting areas, topography, soil, vegetation, etc.—but they also consider the political and social environment that they are leaving behind and the one they are entering into. This means that political leaders must weigh the possible risks and benefits that will confront them when they move from a region where they know and can generally predict what kind of social relationships they will have with neighboring Yanomamö groups and move into an area where their social and political relationships with new neighbors are less predictable or knowable in advance.

In a word, one of the most important and salient dimensions of their “ecology” is the social dimension—the kind of constraints, costs, risks and opportunities that they will have to deal with because of the nature and relative power of their human neighbors (Chagnon, 1968b). Thus, their warfare practices and political strategies have an important effect on their distribution geographically and their general patterns of settlement movement through their virgin tropical forest niche over time (ibid; Chagnon, 1974).

Let me briefly summarize some of the more ‘palpable’ aspects of this “political” (military) dimension of Yanomamö cultural adaptation before turning to the equally important, but more “ecological” and geographical, aspects of their population explosion and settlement dynamics. This summary is intended to provide the sociopolitical background within which fundamental decisions are made by the Yanomamö leaders to “fission” from a secure village and elect to move into an unknown and unpredictable new “environment.”

It is important to keep in mind that the following summary “concentrates” 125 to 150 years of demographic and political events of the Yanomamö villages of this region into a vignette. Critics who fail to see, on the basis of short-term visits to the Yanomamö, any or all of what I report in the following “historical” sense occasionally jump to the conclusion that I am “exaggerating” Yanomamö warfare and violence. While I haven't “seen” all of the events in person, I have, over 25 years, witnessed enough of them to lead me to conclude that the many hours of tape recorded accounts of who did what to who in the past (or in villages I had not been in) substantiates what the long-term pattern is: a chronic history in most villages of one war followed by another and an apparent chronic “jockeying” for desirable locations that have both natural and cultural attributes.

Most of the statistics on mortality due to violence reported below were initially published in Chagnon, 1966, 1974, and especially 1988.

First, violence takes a heavy toll in this area and, because of this, political decisions entail potentially very high costs. From my experience, it is their concern over warfare and the costs that this entails that weighs most heavily in the decisions made by Yanomamö leaders to fission and move into a new area where neighbors there are less predictable than those in the original area. Approximately 30% of all deaths among adult males is due to violence of some kind, usually lethal

raids on enemy villages (Chagnon, 1974; 1988). That is an extremely high rate of death due to violence by world standards, but substantially lower than rates reported for other pre-contact "tribal" societies and well-studied Western nations and cities (Knauff, 1987; Daly & Wilson, 1988). Second, 44% of all males estimated to be 25 years old or older have participated in the killing of another human being. While most individuals have participated in the killing of only one or two individuals, a handful of men have killed 10 or more enemies. One man, who holds the record in my data, killed 22 individuals. This does not mean that the Yanomamö are extraordinarily "vicious" or "bloodthirsty;" it is simply that they live in a cultural environment where violence is common, frequently used by all, and often needed to defend one's self and close kin. They have no police, courts, judges, or constituted legal system with coercive authority. Kinship obligations and self-help determine one's reaction to the affronts and threats by others...as well as establishing one's security and status. Third, approximately 67% of all individuals over age 40 have lost, due to violence, a very close (genetic) kinsman: a parent, sibling, or child. The level of blood relationships in all villages—"inbreeding"—is such that the death of a single individual 'bereaves' a large number of closely related co-resident kin. The most dramatic consequence of this fact is that the revenge motive is extremely salient: there will be, in all villages, a determined cluster of close relatives of the slain victim who want to exact lethal revenge for any killing, thus perpetuating into long vendettas any single act of lethal violence by acts of counter-violence. To refrain from violence in this milieu is to invite further predation.

Thus, the potentially high social and political costs associated with the Yanomamö "environment" require that village leaders take these into consideration as they contemplate remaining in their present location or moving to a distant area where they are less able to predict their relationships with new neighbors and potential allies—or enemies. In general, the severity of risks and costs of warfare increase in proportion to the decline of relatedness, historically and genealogically, between conflicting villages (Chagnon, 1974): at the extreme violent end of this spectrum is the "nomohori," the "treacherous feast" (Chagnon, 1968a & b; 1983[1968]). This refers to a situation in which one village persuades a "neutral" village to invite an unsuspecting group to attend a feast and, during the feast, both groups attack the visitors and kill as many of them as they can (Chagnon, 1983[1968]). In general, this tends to occur only when the two primary groups involved are either unrelated or only remotely related.

PRACTICAL AND THEORETICAL PROBLEMS FOR GPS AND REMOTE SENSING

Previous Practical Problems and New Solutions

A major difficulty to date in arriving at a satisfactory description of the problems of the cultural ecology of Yanomamö warfare, let alone a generally acceptable explanation of them, has had to do with the following three factors.

Maps. For the early period of my field research, when I began realizing that the data did not conform to then current theoretical predictions, my work was handicapped seriously by the lack of accurate maps of the region. There was considerable variation in the location of major rivers on even official maps provided by the Venezuelan Cartografía Nacional office. Thus, the Mavaca River, in the heartland of my research area, was sometimes shown as a relatively short river flowing in a northerly direction on some maps, but as a much longer river whose headwaters began near the headwaters of the Orinoco River and the course was generally east to west in the headwaters,

changing to a northerly course only in its lower reaches. Many of the important political and demographic events I was studying took place, according to my informants, "in the headwaters of the Mavaca River."

The situation improved markedly in 1972/3, when the Venezuelan Government commissioned the Aerospace Division of the Goodyear Corporation to make SLAR maps of this region. The hydraulic interpretations of these maps radically improved our knowledge of the actual courses and termini of the major rivers. Unfortunately, maps made from these data were not easily obtainable for a number of years after they were made—and I have still not obtained access to the original digitized SLAR data that exists, data that would improve our understanding of Yanomamö settlement patterns in a geographical context.

The SLAR maps also provided very important information on terrain, distinguishing as they did regions of rugged mountains and hills from flat, penneplane regions and broad undulating river basins. To date I have been able to obtain only large-scale copies (1:500,000) of these maps, invariably distorted by the blue-print or xerox copying methods used to produce them, thus making them only marginally useful for detailed analyses of the relationships between aspect, slope, and elevation and the locations of the numerous ancient Yanomamö village sites. Still, visual inspection of the village locations on maps derived from 'hydraulic interpretations' of the SLAR maps, taken with the separate SLAR relief maps, indicates that there will be important correlations as described below. Imagery from the Landsat and Spot satellites will also immensely improve our understanding of the relationships between settlement locations and geographical variables. Unfortunately, the latter imagery could be more costly than normal because the region is cloudy for much of the year and adequate coverage of the relevant areas may require taking segments from several different satellite images made at different times.

Finally, the current SLAR maps are not as accurate as they could be for the purposes of studying the dynamics of Yanomamö population movements in space: they will have to be "rubber-sheeted" so that the map coordinates coincide more precisely with features whose locations have been determined by G.P.S. instruments in the field. For example, in August 1990 my Venezuelan co-researcher, Charles Brewer-Carías, and I determined the longitude and latitude of a prominent mountain peak in the Siapa River basin with several different fixes on different dates. When these data are used with the published coordinates on the SLAR maps, there is a 3 minute error in the latitude of the location of this mountain peak. We obtained similar data for a different mountain peak approximately 20 miles to the west of this, again discovering about a 3 minute latitude error in that mountain's location when plotted from the coordinates on the SLAR map—but in the opposite direction. Thus, the sum total of error is approximately 6 minutes over a relatively short distance for this region of the SLAR map.

Travel Difficulties. Until August 1990, I had to travel over this area by dugout canoe and on foot, guided by very poor, highly inaccurate maps. In August, September and October of 1990 I was able, for the first time, to make extensive overflights of the area in helicopters,⁵ an experience

⁵ A private electric corporation, CADAPE, generously provided us with a small helicopter for our research in August. The Venezuelan Government, in collaboration with a private foundation, FUND-AFACI, generously provided us with larger Venezuelan Air Force helicopters in September and October.

that provided me with new impressions of the general relationship between Yanomamö village and garden locations and the kinds of terrain in which they tend to be found.

Travelling by canoe and on foot is very slow, tedious, and time-consuming. It also gives you a limited perspective on the nature of the terrain you are travelling in—you see, in general, just the immediate 100 meters or so around you and, therefore, have a very poor understanding of the overall terrain out of eyesight. You could, for example, canoe or walk within a half-mile of a 7,000 foot mountain and never know it was there. Indeed, you would not know in most cases if you are walking or canoeing through a relatively flat area with a few hills, or an extremely hilly area with just a small amount of flat-land through which you are travelling by canoe.

For purposes of the essential demographic research and census updates of current villages, this is an extremely inefficient way of doing field research. The use of helicopters has recently made it possible to visit a much larger number of communities in a short time, communities that would have taken several months and several field trips in different years to reach by canoe and on foot.

During the projected research, we will be visiting many, often very widely-dispersed, villages by helicopter. This will lead to a dramatic improvement of demographic data, since many different communities, including yet-uncontacted ones, can be visited and censused in the same season—and these data quickly updated on return visits the following year(s). Moreover, travel by helicopter will also make possible radical improvements of our knowledge of the exact locations of ancient community sites, since informants in each area will guide our helicopter flights in those areas to locate and obtain G.P.S. fixes on more important ancient gardens and the more significant cultural-geographical features (mountains, rivers, etc.) frequently mentioned in native accounts of village migrations and political histories. These data will also be useful in correcting the existing SLAR maps, i.e., making the coordinates of the features consistent with the grid system.

A comment on methodology and helicopter transportation is in order at this point. Yanomamö villages are normally located in the area cleared for their gardens. Portions of these gardens are “new,” i.e., the trees are cleared and the new plantings are young. It is normally possible to find an area within the garden that is clear enough for the helicopter to get close to the ground—close enough to allow one or more of the researchers to rapel by rope to the ground and enlist the help of the villagers to clear a suitable site for the helicopter to land an hour or so later, bringing the supplies and equipment needed for a team of researchers to remain there for several weeks.

In short, a major travel problem has now been solved: our FUNDAFACI sponsors and the Venezuelan Government has generously agreed to support our research effort by providing us with gratis helicopter support, something that will lead to very dramatic improvements in the demographic and geographic aspects of Yanomamö settlement and military history. The projected research among the Yanomamö in this area is likely to result in the most detailed study of an expanding human population that is caught up in the throes of an agricultural ‘revolution,’ a population that is also currently conducting native warfare practices without intervention from nation states.

Informant Accuracy Regarding Geographical Locations. The third research difficulty up to this point has been the limitations imposed by native informants’ abilities to accurately specify the locations of distant villages, gardens, or geographical features. The Yanomamö travel exclusively on foot and ‘navigate’ by a combination of familiarity with local landmarks and the position of the sun.

They tend to follow very direct courses from their village of origin to some distant village they are going to visit, often walking straight up a steep hill and straight down the other side—instead of zig-zagging along the hill and saving energy. They have a very limited vocabulary for precisely specifying distances, which they measure in “sleeps:” their number system is “one, two, and more-than-two.” Anything larger than two must be indicated by counting with fingers, the accuracy of which diminishes almost logarithmically after three fingers of “sleeps” are involved. For example, a village that is a 5-day walk away might be estimated as 5 fingers by one informant, 4 fingers by the next, or 7 fingers by another. In addition, their accuracy at specifying direction by pointing appears to diminish rapidly if the location of interest is more than a two-day walk away.

For the past 27 years I have been ‘determining’ the locations of geographical landmarks, ancient village sites and migration routes by asking informants to point out the direction to these locations and then recording these with a hand-held magnetic compass. I obtain the distance to these sites from where I am standing by getting the number of “sleeps” required to reach them. I also supplement these two pieces of information by asking for the name of the river or mountain that the site in question is near, something they can specify reasonably accurately and consistently (from one village to the next) without recourse to distance or time concepts. I have determined the approximate locations of some 500 important village locations in the research area using these methods, which, given the current penchant for acronyms among those inspired by GIS approaches, might be characterized as SAPS: *Stone Age Positioning System*. I have done this at some 20 or so widely-separated locations, for approximately 500 different locations of interest. Unfortunately, for some of the locations where I took bearings and distances in this fashion I did not know where it was that I was standing at the time I recorded the data. I knew, for example, that I was 6 hours by trail inland, to the west of, the headwaters of the Mavaca River. But, as mentioned above, if the Mavaca headwaters are somewhere near the Orinoco headwaters, as indicated on earlier maps of Venezuela, the resulting information would be next to useless if the Mavaca headwaters, as indicated on more recent, SLAR-derived, maps was 80 miles further to the west. However, I can now return by helicopter to the sites where I took all these earlier bearings and distances and fix the positions by GPS. This will enable me to convert many of the previous inaccurate locations to much more accurate locations for sites that are located within a few hours’ walk of the original site, since informant errors are very small if the distance to the site in question is less than two days’ walk. For example, for all the time/distance measures to distant gardens I recorded at a place called Mamoheböwei, whose own exact location I did not know when I was living there and took these readings, many of them will be now very useful when I determine the location of Mamoheböwei with a GPS fix—which I can do from a helicopter. The locations of garden sites that were described as within a few hours’ walk from Mamoheböwei will be more precisely known if I know more precisely where Mamoheböwei is, which is now possible by using GPS instruments.

In this fashion, only a fraction of the 500 garden sites revealed to me over the past 27 years will have to be located by returning to them or flying over them with helicopters and GPS instrument. Many of the remainder are gardens said, by informants, to be located “right next to” other gardens. How large that fraction is remains to be determined in the projected research.

Theoretical Problems: Why So Much Warfare and What are the Relevant Variables that will Explain it?

The southwestern Yanomamö are undergoing rapid population growth and geographical expansion,

generally into virgin tropical rain forest that is either uninhabited or sparsely inhabited. These processes are taking place among an essentially "neolithic" native population in the context of indigenous warfare patterns, the last place on earth where this is true. Population densities are extremely low for cultivators—between 0.10 and 0.30 persons per mi.², i.e., in the general range of hunter/gatherer populations. Several sources of information imply that food shortages are not a serious issue. Biomedical and nutritional data indicate that the Yanomamö are well-nourished compared to other group (Neel, 1970). The fact that their population is growing rapidly is an indirect indication that they are not pressing against "carrying capacity," at least insofar as food items are concerned (Chagnon & Hames, 1979 & 1980; Chagnon, 1988; 1990b). Finally, direct ethnographic observation and native accounts does not lend credence to arguments that their fighting is provoked directly by scarcities of strategic material resources such as hunting territories, land, water, or technologically significant items needed for manufactures. These peculiarities—low population density and relatively intense warfare in the apparent absence of scarcities of strategic material resources—have led to what some colleagues characterize as a "classical" debate between me and advocates of the cultural materialist approach, Marvin Harris' version in particular (Harris, 1974; 1979; 1984, and elsewhere; Ferguson, 1989; Ross and Ross, 1980; Chagnon, 1974; 1988; 1989; 1990a; Chagnon & Hames, 1979; 1980).

My recent (Summer/Fall, 1990) and projected research will shed new light on this debate. In August, September and October, 1990, I obtained GPS instruments that enabled me to precisely locate critically important village sites, abandoned gardens, and rivers whose previous locations were only vaguely known prior to this. In addition, I was able to fly over large regions of the area by helicopter, gaining an additional perspective regarding the proximity of crucial headwater regions to each other and a better sense of geographical relief, topography, and probable difficulties in travelling between key areas frequently mentioned by the Yanomamö in discussions of village histories.

One discovery, by simply "eyeballing" the areas from a helicopter where many of the demographic and political events of the southwestern Yanomamö transpired was that there appeared to be a small number of regions that had very broad similarities and that a large fraction of the some 400-500 ancient garden sites I know about seemed to be concentrated/clustered in these areas. This general impression was largely made possible by fixing more accurately the relative locations of ancient gardens, with Yanomamö informants who flew in some of the helicopter flights with me, using GPS instruments. When the sites were placed on a map, they concentrated in several geographical areas that seem to share a common set of topographic attributes. Two of these areas in particular have very large numbers of abandoned gardens and I will provisionally refer to these two areas as Core Area A and Core Area B respectively. In addition, several other regions have clusters of abandoned gardens, although not as many. These regions appear to basically be major routes of migration followed by groups that left the major "Core" areas, although some of these regions presently include villages. Map 1 provisionally describes "core areas" and "regions."

CORE AREAS, ADJACENT REGIONS, AND THEIR POPULATIONS

Discussion of "Core Areas" shown on Map 1. Let me emphasize at the outset that all maps provided in this paper are to be taken as provisional and that they should be viewed as a summary of research to date that was based on techniques and methods, as described above, that are clearly imprecise and now very much outdated. I summarize a fraction⁶ of these data here, in published form, for a special reason: I would like to know the extent to which the "newer" remote sensing techniques will improve the accuracy of our current understanding of village and garden locations, presently based largely on "SAPS," as the projected research develops.

Let me now briefly comment on some of the areas shown in Map 1.

First, I do not know if the concept "core area" will be an empirically sustainable hypothesis once more data, especially remotely sensed data, are utilized in this project. Second, even if the hypothesis of "core areas" is empirically defensible, I do not yet know how many of them can be adequately demonstrated with yet-to-be-collected new data. Map 1 shows two areas that I provisionally designate as "Core" areas, along with a number of adjacent regions that are based on the political and settlement histories of the groups located in them at the present time.

Core Area A. This area seems, on the basis of all my demographic and political history data, to be the most significant area in the southwestern Yanomamö region. Many of the ancient garden sites at which the oldest members of villages located in other regions of Map 1 were born are located here, and here also are the ancient gardens mentioned in many of the political histories provided by many informants in many villages far removed from this area. There are literally scores of ancient gardens in this area, only a fraction of which are shown on the blow-up maps below.

At least two major Yanomamö multi-village populations originated here within the memories of my oldest informants, perhaps others as well (see below). One of these is the sub-population I have previously labeled "Shamatari" (Chagnon, 1966; 1974; 1983[1968]). It would be more appropriate to redefine this group as a segment of a larger population that will henceforth call the "Aramamisi-teri" population block. Aramamisi is the name of a mountain near the Orinoco River (at about 2° 30' N by 64° 30' W), as well as the name of an ancient village that subsequently fissioned into many groups whose current descendants basically comprise all the villages in Core Area B and the regions indicated as 1, 2, 3, 4, 6 and probably 7 of Map 1 (Chagnon, 1966; 1968b; 1974). It is also possible that some villages currently located in region 5 of Map 1 also derive from this population, e.g., the villages known today as Boreta-teri and its splinter, Koroboreböwei-teri. In addition, several large villages known to presently exist in Brazil can be traced back to Core Area A. This area is essentially a "population pump."

The Yanomamö in this and in adjacent regions use the term "Aramamamisi-teri" to refer to most other villages that came from this core area, but there are troublesome contradictions that only projected field studies can resolve. For example, many informants will allude to the members of a

⁶ Time constraints have not allowed me to go through all of my earlier maps and data on Yanomamö village and garden sites. Thus, only a fraction of them are included in the maps presented here.

Map 1: Core Areas

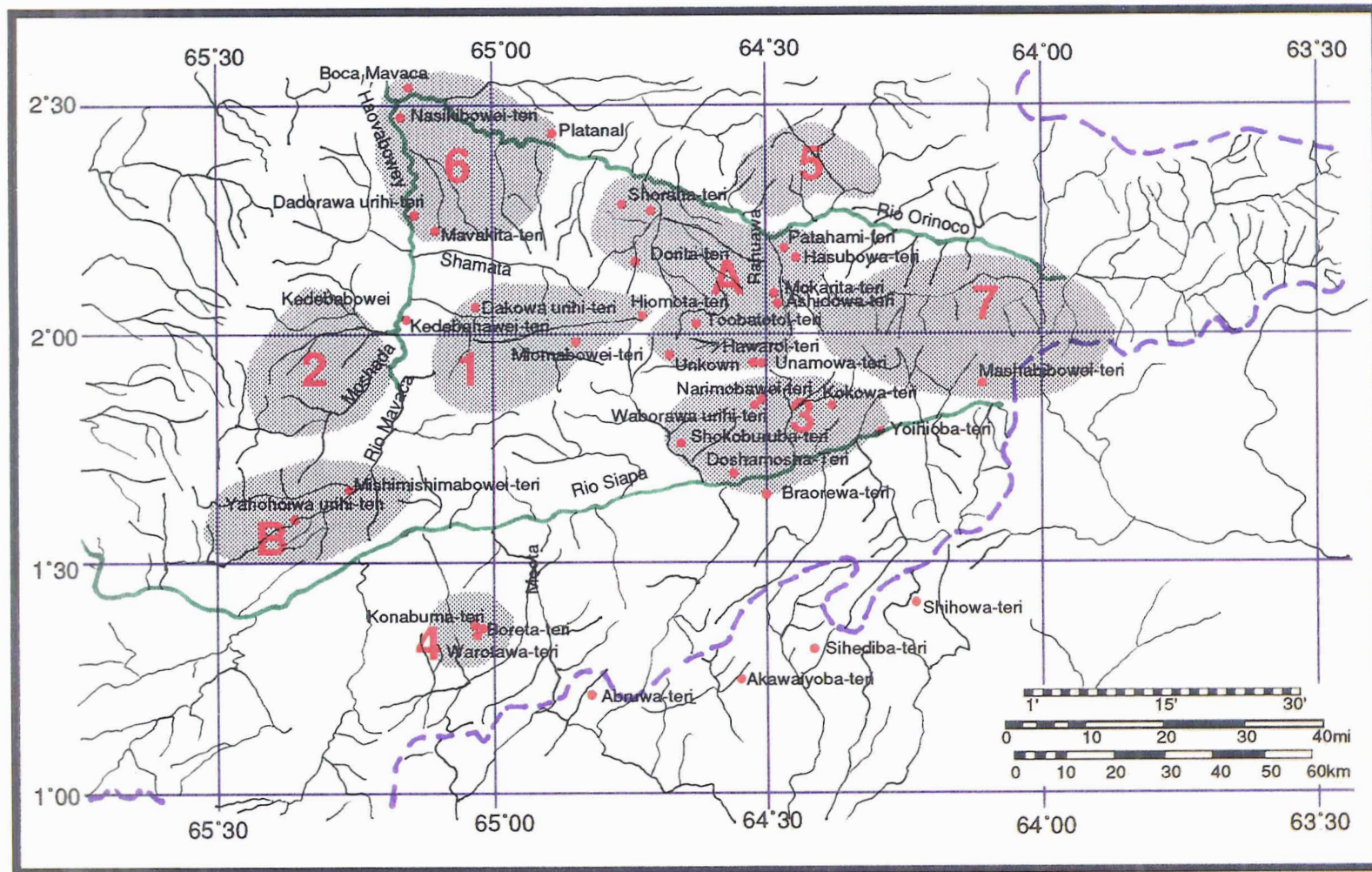


Figure 1. Map of Core Areas A and B Adjacent Regions

specific village as being "Aramamisi-teri" in some contexts, but later contradict themselves and deny this identity in other contexts. Here is where detailed genealogical data on ancestors will be very important; it will resolved the issue of common descent, and shed light on the sub-tribal 'classification' by the Yanomamö of other groups in particular contexts (viz. Chagnon, 1974, for a discussion of manipulating group identities for political reasons).

The second major multi-village population to originate here is the group I have previously referred to as the "Namowei-teri" (Chagnon, 1966; 1974; 1983[1968]). At the present time there are three Namowei-teri villages in Core Area A: Dorita-teri and a new splinter of that group, and Sheroana-teri. All three were once a single village known as the Patanowä-teri (Chagnon, 1966; 1974). These three villages numbered 228 individuals in 1987, the date of my last census.

The several villages in region 6 (about 500 people as of my 1987 census) are also fissions of the Patanowä-teri group (Chagnon, 1966; 1968b; 1968[1983]; 1974). All groups in region 6 are now in direct contact with Salesian missionaries at the mouth of the Mavaca River and most of them have been for over 25 years. In 1964, when I began my field research at the mouth of the Mavaca River, there were just two villages there—recently fissioned from each other. Today there are at least a dozen small villages, mostly derived by fissioning from the two original villages, but supplemented with migrants from more distant Yanomamö groups.

Core Area A currently contains a number of other villages that have been mentioned frequently by informants who have provided me with the political history of much of this region (Chagnon, 1966; 1974). I have spent some time living in and studying the Hasuböwä-teri and it's splinter group, Patahami-teri between 1964 and 1974. At that time their combined population (by my census count) was approximately 225. Closely related to them and recently fissioned from them are the Ashidowä-teri and Mokarita-teri, probably another 200 individuals. These four groups originated in region 5, as did the several Namowei-teri groups, and number approximately 400 to 450 individuals at the present time.

Also in this area are two closely-related but poorly known villages, Hawaroi-teri and Unamowä-teri, groups that have periodically fissioned from each other and then rejoined. In 1990 they were living in the same village, having rejoined as a consequence of a serious epidemic that decimated both groups. Both are considered to be "Aramamisi-teri" by informants in neighboring villages.

Especially problematic in this area is the village known as Toobatotoi-teri, a yet-uncontacted, relatively large village. They are frequently mentioned to me by informants as long ago as 1965 (Chagnon, 1974:84). I met several men from this village in 1986 when I was living in a village in region 1: they visited there. I also spotted their village from the air in 1990 and established it's location by GPS. It was large, probably in the range of 200 individuals. Later in 1990 I briefly visited, by helicopter, Dorita-teri, a village in Core Area A, whose residents I have known since 1964-5, and learned from them that the Toobatotoi-teri had recently fled to a very hilly region and were living in a temporary shabono to avoid their enemies, one group of which had recently raided them and killed their headman, Natemösököwä. The man who killed him lives in a village in region 2 (!) and is well-known to me. This man (and all of his co-villagers) had never had any previous contact, at least in recent times, with the Toobatotoi-teri, yet they raided them and killed the headman in early 1990.

What is problematic about Toobatotoi-teri is the uncertainty surrounding its earlier history and population identity: some informants say they are "Aramamisi-teri" while others, usually "Shamatari" informants, say they are "Namowei-teri," the two major populations I described in my 1974 book. It is very unlikely that they are Namowei-teri, a group whose history I know in considerable detail (See Chagnon, 1966; 1968b; 1974).

Another problem in this area is the identity of a village I spotted by helicopter several times in September, 1990. Its approximate location is marked "Unkown" on Map 1—each time I spotted it there were insufficient satellites available to obtain a GPS position for this village. I do not presently know the identity of this village, but it could possibly be one of several villages I know from previous research in this area, i.e., a relatively recent splinter of a group I already know. From the air the village looks like it might have a population of approximately 125 people.

Region 1. This area currently contains 3 villages, all of which I have previously contacted and studied to various degrees of intensity. I made first contact with these groups in 1971 (Chagnon, 1974), at a time when none of them had ever before seen an outsider. They were known in 1971 as the Iwahikoroba-teri and were located at the south end of Region 1. They have subsequently fissioned into three villages, numbering 109, 70, and approximately 120 respectively, i.e. slightly over 300 people.

Region 1 is also a 'route' that has been followed by at least three Yanomamö populations that have migrated out of Area 1. The first of these is a group known as the "Kohoroshitari," a poorly known population that moved through this area about 1900 and whose current descendants live in Brazil, probably the groups that currently live on the Cauabury River and its tributaries (See Biocca, 1970). The Kohoroshitari figure in the earliest history of the "Shamatari" groups I have frequently described, i.e., the groups currently located in Core Area B and region 2 of Map 1. Shamadari informants from both of these areas know relatively little about this group, except that they fought with them periodically and that they moved through the Mavaca headwaters as they migrated into the area to the south. While they know the names of some of the more prominent leaders in this group, they know little about their genealogies.

The second group to move through this area is the "Karawatari" population, also a poorly known group and somewhat enigmatic. Shamadari informants know more about the Karawatari and can name individuals who were "prominent" in it, and provide additional but limited genealogical data on some of these individuals. The reason for the latter is that some "Karawatari" remained behind or married into the Shamadari group, i.e., some of the Shamadari have Karawatari ancestors. The Shamadari also know, probably because of this "mixture" with Karawatari, specific areas where the earlier Karawatari populations cleared gardens. Some of these areas were later re-cleared by the Shamadari.

Finally, the "Shamatari" proper, i.e., those Yanomamö who currently live in Core Area B (and those in region 1), moved through this region from ancestral sites in Core Area A.

Core Area B. This area currently contains two villages: Mishimishimaböwei-teri and a recent (post 1985) fission group located upstream from the main group. The total population of the two

groups is approximately 200 people (as of my 1987 census).

This area also contains scores of ancient gardens, most of them cleared by the ancestors of the current Mishimishimaböwei-teri and/or groups that fissioned from them in the past and moved into region 2 and 6—and two groups not shown on this map. It also contains ancient gardens originally cleared by both the Kohorshitari and Karawatari populations as mentioned above.

This area also appears to be a “population pump” like Core Area A, but perhaps to a lesser extent. The “Core-ness” of this area is basically based on the fact that very large numbers of ancient gardens are clustered here (see blow-up map of this area, below). Compared to Core Area A, however, it has been the “demographic pump” of a smaller number of Yanomamö. It remains to be seen if the ecological and geographical features of this area are as similar to those in Core Area A as my impressions at this point indicate.

Region 2. This area recently contained two villages, Kedebaböwei-teri and Haoyaböwei-teri. The former recently moved out to the Mavaca river as shown, while the latter group migrated into the area immediately to the north...just outside the area shown as region 2 on the map (and live at the villages indicated Mavakita and Dadorawä-urihi-teri). The total population of the two groups is approximately 225 people, of which Kedebaböwei-teri includes 170. The members of Haoyaböwei-teri have recently moved to be closer to the Salesian Mission at the mouth of the Mavaca, especially an “outpost” of that mission, “Mavakita,” located approximately 1/3 of the way up the Mavaca River.

Region 3. This area contains three current villages, all derived from the major group known as Doshamosha-teri. The total population of all three groups is approximately 325 individuals. I contacted the two largest of these groups in August and October, 1990, and made a complete census of them. The third group is yet uncontacted, but will be visited in 1991. Its population is estimated to be approximately 75 people on the basis of a preliminary genealogy of the group provided by informants in the other two related villages.

At least four other villages are found within the confines of this region. Two of these are known as Narimöböwei-teri and Wabörawä-urihi-teri and are located on twin peaks, within sight of each other, on the mountainous ridge separating Core Area A from region 3. They have also been mentioned to me by informants in other areas as far back as 1964-6 (Chagnon, 1974). I briefly visited one of these groups in August, 1990: it had a population of 124 individuals. I never visited the second group, within a mile or so away, because of time constraints. It probably contains 75 to 100 people; the headman of the 2nd, unvisited group, Wabörawä, was visiting in Doshamosha-teri when I spent about 3 weeks there in August 1990, and was one of my primary informants. These two villages number approximately 200 people.⁷

Immediately to the east of them are two other villages: Kokowä-teri and Yeihioaba-teri, both unstudied. The Yeihioaba-teri were briefly visited by French Anthropologist Jacques Lizot in 1973

⁷ I visited the village here designated with a population of approximately 120 inhabitants. I photographed and counted 109 individuals there in 1987, but a small fraction of the village had left for a trek; my estimate of 120 includes this faction whose members I did not actually photograph and census in 1987, but of whose existence I am sure because of genealogies collected in the village and their (empty) sleeping places on the detailed diagram I made of the village.

(Lizot, 1974), which then had a population of 63 people. The Kokowä-teri are yet uncontacted. Both of these groups, probably together numbering 150 or so people, appear to be related to the Narimöböwei-teri and to groups further to the south, in Brazil, that also appear to have migrated out of Core Area A. A problematic feature of these groups is the fact that some informants in other villages claim they are all "Aramamisi-teri" while others are more equivocal or less certain of this identity for them. These four villages include approximately 325 to 350 people. If they are included in region 3, then this area contains approximately 650 individuals distributed in 7 villages. There is some reason to place two of the latter 4 groups in region 7 and the other two in Core Area A (see below).

Region 4. There are 3 closely-related villages here, all fission products of the same larger village: Konabuma-teri. I have previously discussed the post-1960 history of this group under the name "Yeisikorowä-teri" (Chagnon, 1966; 1974). I visited the largest of the three groups in September, 1990. The two other groups were located within an hour or two from this location. One of these visited en masse—men, women and children—and I was able to get a near-100% census of them on this occasion. The third group was slightly further away and on somewhat strained terms with the local group, but most of the adult men and male children visited and I made a photographic census of them and obtained names and approximate ages of those who did not visit. The two censused groups numbered 94 and 74 respectively. Only 19 men and boys from the 3rd group visited, but I would estimate the total village to contain about 50 people. The total size of all three groups would be approximately 225 to 230 individuals.

The village immediately to the south of them, Abruwä-teri, is located in Brazil. It's inhabitants also originated in Core Area A and they are Aramamisi-teri in origin. I collected a preliminary genealogy of this group in Konabuma-teri and estimate it's population to be at least 200 people, perhaps 250. They are related to the Konabuma-teri and probably fissioned from them relatively recently.

Most of the ancient sites in region 4 are relatively recent occupations by the members of the three Konabuma-teri villages I visited in 1990. It seems to be an area of more recent occupation, but possibly also the route followed by earlier Kohoroshitari and Karawatari migrants who are now located further to the south and southwest in Brazil.

The villages in regions 3 and 4 are probably the most suitable ones on which "comparisons" to those currently found in Core Area A can be made. They seem to have been 'expelled' from Core Area A and seem also to differ in certain political and demographic attributes (see below).

Region 5. This is the "ancestral" area of the groups that eventually moved into Core Area A. It is possible that a few villages in this region, such as Boretä-teri and Koroboreböwei-teri, are related to the "Aramamisi-teri" groups that originated here. It is also possible that villages currently located as far away as the Ocamo River (not shown on this map) are related to the "Namowei-teri" (now in Core Area A and region 6).

Region 7. This is a large question mark at this point. This region is essentially unexplored, but there are a number of Yanomamö villages in it. Some of these are likely to have originated from the "Aramamisi-teri" stock. It is also possible that the Toobatotoi-teri, the problematic village mentioned in Core Area A, might be related to the groups in this area. Projected research in 1991 will entail helicopter visits to one or more villages in this region.

Summary of Demographic Data

Virtually all the people in Core Area B, regions 1, 2, 3, 4, and 6 originated from Core Area A—all within the past 125-150 years or so. By reasonably accurate census figures, this is about 3,100 individuals currently alive in 1991. To that we must add approximately 80 people at the TamaTama mission on the Orinoco and the related Reyaboböwei-teri population on the Casiquiari, another 125 or so. It is clear that the members of the Brazilian villages of Akawaiyoba-teri, Sihediba-teri, and Abruwä-teri also originated in this region in recent times, perhaps another 500 individuals. That brings us up to approximately 3,800 individuals. These figures do not yet include any of the “Kohoroshitari” or “Karawatari” groups that are known to have come from this area as well. And, if any of the groups in regions 5 and 7 also derive from this region, the numbers are even larger, perhaps significantly larger. It is possible that more than 5,000 of the currently living Yanomamö can be genealogically traced, through their recent ancestors and recent political histories and migrations, back to what I have indicated on Map 1 as Core Area A. That would amount to approximately one fourth of all known living Yanomamö if their total population is 20,000 in both Brazil and Venezuela. Clearly this Core area is of extreme importance in understanding the history of a very large fraction of the total number of known Yanomamö.

SYNOPSIS OF MIGRATIONS AND FISSIONS

Map 2 subdivides the southwestern Yanomamö populations into smaller regions for purposes of showing the overall patterns of population movements over time and space, showing how the Aramamisi-teri and Namowei-teri populations have spread, during the past 100 to 130 years, into the Siapa and Mavaca basins. I have published similar map summaries of many of these population movements in the past (Chagnon, 1966; 1968b; 1974; 1983[1968]).

The projected field studies will have three foci.

First, it will establish village and garden locations in the eastern and southeastern portions of the region shown here, areas of occupation about which less detail is known. We hope to identify more accurately the geographical provenience of villages there, determine their current sizes, and establish their genealogical connections to each other and to villages already known in some detail.

Second, it will locate more precisely the hundreds of gardens known to exist in all the areas discussed above, gardens whose locations are only approximately known at present. GPS instruments and helicopter overflights will be primarily used to establish these locations, with Yanomamö informants guiding the pilots. Maps 3 and 4 provide very approximate locations of some of the many gardens known to exist in the two “Core Areas” shown on Map 1.

Third, the projected field research will focus on the demographic, ecological and geographical variables discussed in the remainder of this paper in an attempt to identify and evaluate the most significant variables affecting Yanomamö economy, population dispersal and settlement location.

Ecological and Geographical Features of the Core Areas

The most salient feature of the two “core” areas, noticeable even from aircraft flying at low alti-

tudes, is that they include, minimally, two distinct kinds of topography. First, they include a substantial amount of relatively 'flat' penneplane land—terrain that is either nearly flat or interrupted only by gently undulating hills. Second, these penneplanes are adjacent to areas characterized by much more rugged terrain—low mountains (2,000 to 5,000 feet above the adjacent plain) with steep slopes.

One might contend that this is generally true for the whole region....indeed, true for any geographical region with hills and flatlands. A response to this is that the abandoned Yanomamö sites are not concentrated in areas of broad penneplane, such as the vast region immediately south of the Siapa River, nor are they concentrated in regions where the terrain is characterized by high, rugged relief—such as the area immediately to the west of the Mavaca headwaters. In both of these cases, Yanomamö groups have periodically entered these kinds of regions, but have retreated back into the kinds of areas I describe here as "core" areas.

These impressions are reinforced even more when the clusters of garden sites are plotted on SLAR maps of the region. At this point, however, not enough of the some 500 ancient sites known to exist in this general region have been located accurately enough by GPS to warrant firmer conclusions: projected research will determine if the "core area" hypothesis as suggested here is empirically sustainable when more detailed information from satellites and 'ground truthing' are collected during the projected research.

RESEARCH QUESTIONS

The current but preliminary picture, advised by 27 years of previous research on settlement patterns, political histories of villages, recent GPS positioning and helicopter overflights, suggests a number of possible research questions.

- a. Existing demographic data suggests that the "core areas" are, in effect, "population pumps."

That is, groups that have managed to gain a permanent foothold in the more desirable portions of the core areas grow rapidly, fission often, and send larger numbers of "colonies" out of the area when village sizes exceed 150 to 200 individuals. For example, Core Area A of Map 1 has been a key population pump for nearly a century. All the villages shown on Map 1, and some in region 7 not even shown, originated in Core Area A. This is nothing short of astonishing in a demographic sense. It is, however, demonstrable by both informants' accounts of political histories (fissions and migrations) and independently verified by genealogical data that includes birthplaces of all village members and places of death of recently deceased kin of current village members (Chagnon, 1974; ms.) Thus, most of the oldest living individuals in Core Areas B and regions 1, 2, 3, 4, and 6 were born in gardens that are located in Core Area A. I predict that when similar information is collected in region 7 the same will be true there. Finally, an unknown number of Yanomamö villages on the Brazilian side of the border immediately south of the Siapa drainage have migrated there in very recent times; these include Abuwä-teri, Akawaiyoba-teri, Sihediba-teri, Shihowä-teri, and an unknown number of "Karawatari" and "Kohoroshitari" villages. It is likely that the oldest living members of many of these villages also originated in Core Area A. In a sense, Core Area A is somewhat of a demographic "cradle of Yanomamö civilization" for virtually all of the groups now located in the middle to upper Siapa basin, immediately adjacent portions of Brazil, and all groups I have described as "Shamatari" who presently live in the Mavaca drainage (Chagnon, 1974).

Map 2: Summary of Migrations and Fissions

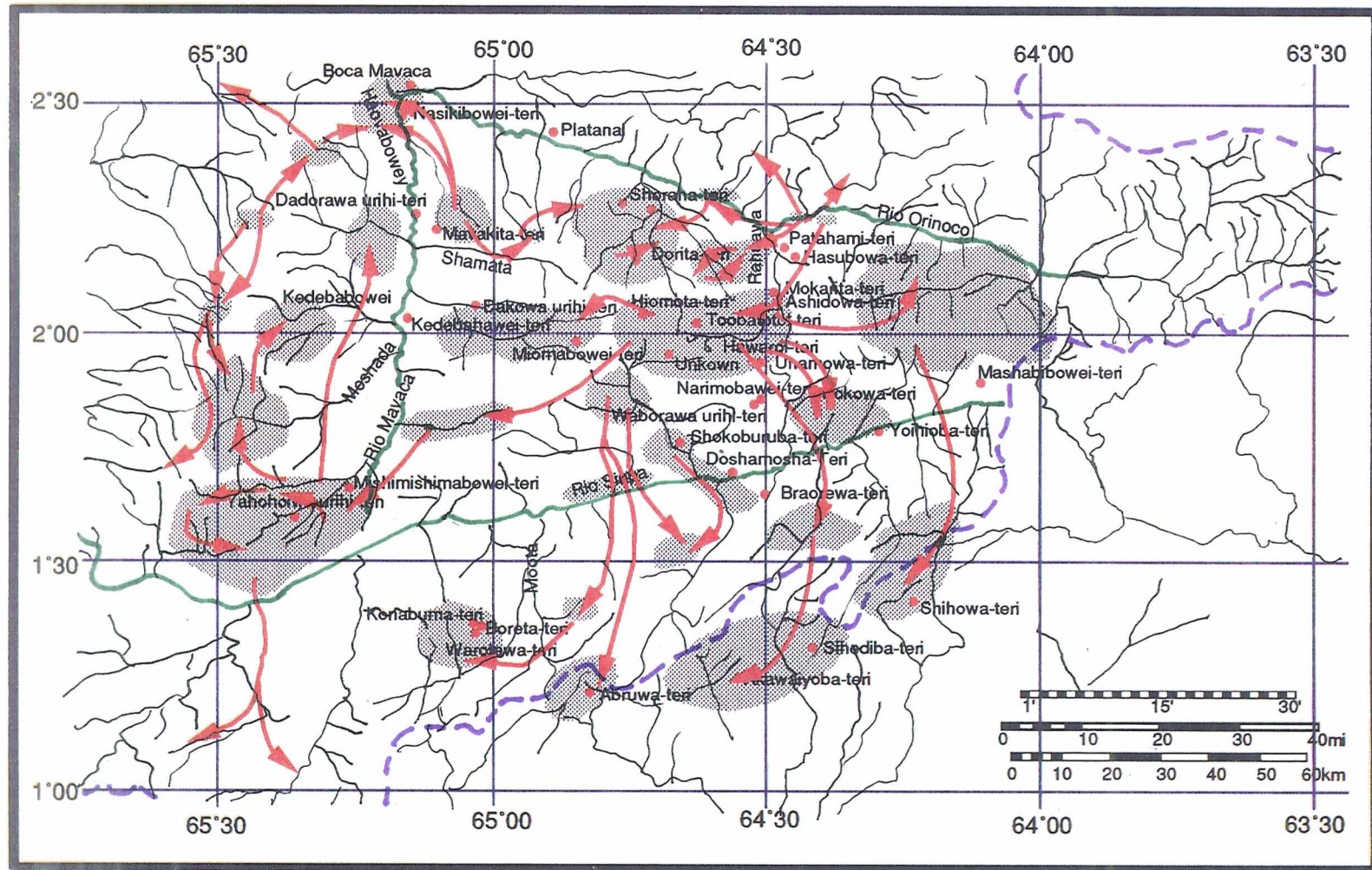


Figure 2. Map showing Migration Routes of Yanomamo Groups in the Mavaca, Siapa and Adjacent Orinoco Drainages

Map 3
Blow-up of Area A

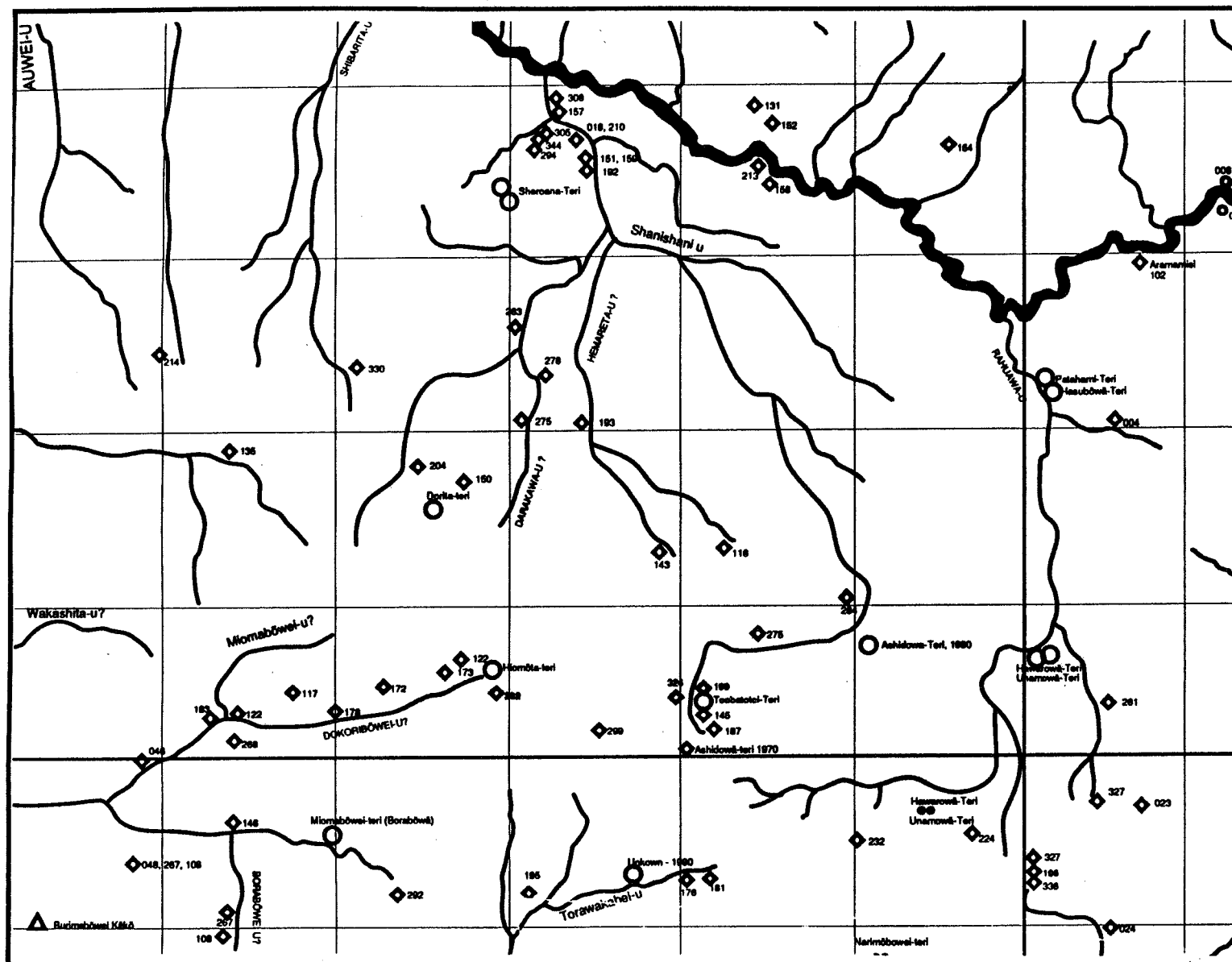


Figure 3. Map showing Current Villages and selected Abandoned Gardens in the Headwater Zone between the Rahuwa, Shanishani, Washawa and Shimakaraba Headwaters.

Blow-up of Area B

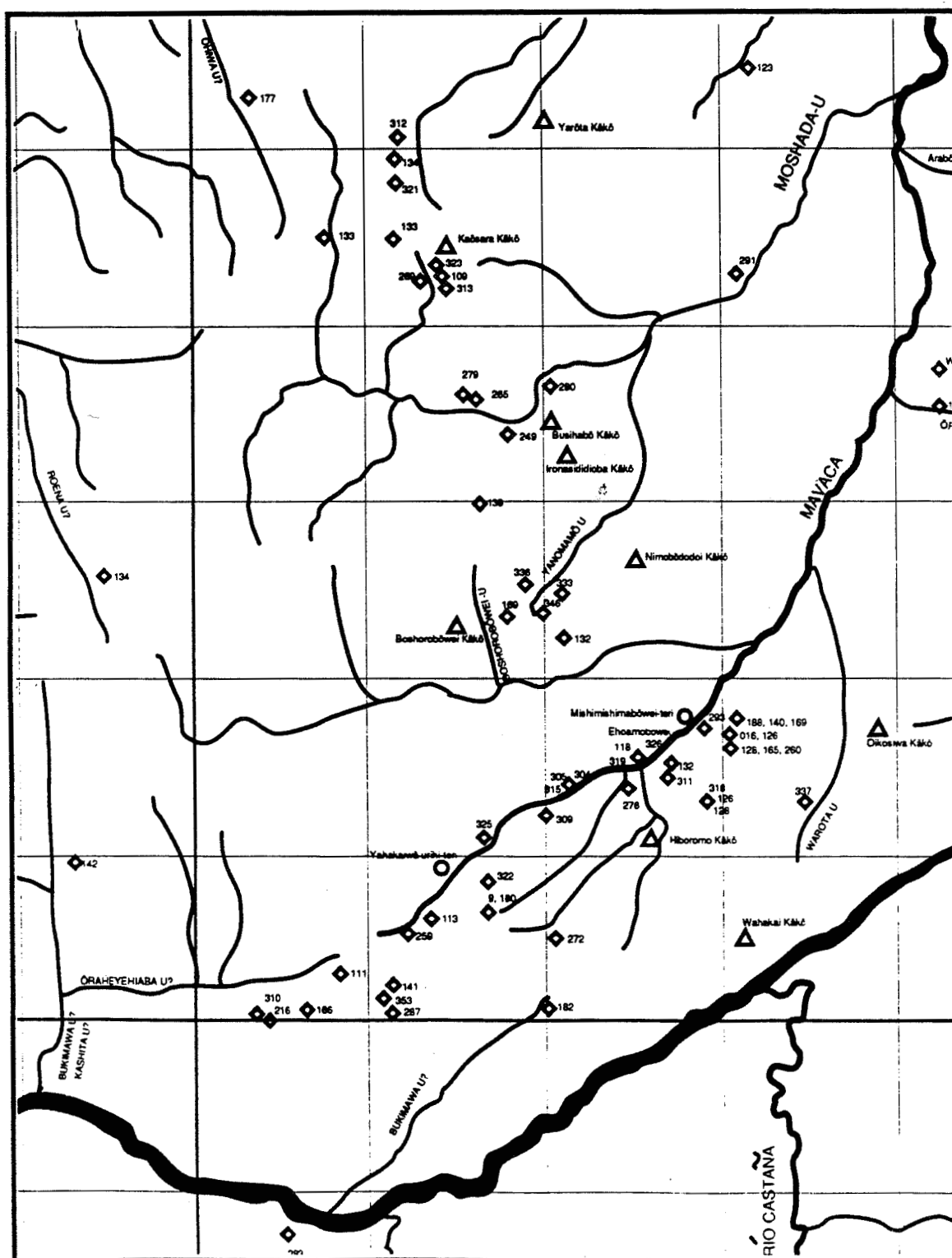


Figure 4. Approximately 50 abandoned gardens are shown here; there are many more. All garden locations are approximate. Eleven currently occupied villages in the Core Area are also shown.

The projected research will result in census data on approximately 20 villages not thus far included in my demographic research. Some of these are found in Core Area A, others in regions 5 and 7. The genealogies of all individuals in these villages will also be collected for at least 3 or 4 generations' depth, along with other biographical and demographic information. Table 1 provides a list of the

Table 1: Biographical Variables on Individuals

**Biographic Variables to be Determined for each Individual
Depending on Sex, Age, or Living/Dead**

01. Name(s) (Including Alternative Names)
02. Sex
03. Age
04. Place of Birth (Garden Name)
05. Father & Mother
06. Spouses (in sequence acquired)
07. Children by each Spouse
08. Place of First Menses (females)
09. Year of Census
10. Village of Residence at time of Census
11. Cause of Death of dead
12. Approximate Age at death
13. Place of Death of Dead
14. Currently cultivating a Garden? (Men only)
15. Who feeds Who (Garden Produce)
16. Orphan, Foster, Adopted
17. Places of Current Residence of Parents, Spouses if not EGO's Resident
18. Residence by Post Number in Village
19. Reasons for Termination of non-current Marriages
20. ID Photograph
21. Unokai status of adult Males
22. Names of victims for Whom Unokaied
23. Reproductive Status of Women (Pregnant, Lactating, Menopausal)
24. Patrilineal Lineage (Generated by Computer)
25. Mother's Patrilineal Lineage (Generated by Computer)
26. Past Infanticides

Gardens: Geo-Political Variables

01. Names of founders
 02. Reason for abandonment
 03. Did a Fission Occur There?
 04. Who Led Which Group and Where did they Next Garden?
 05. Conflicts: With Whom and Over What?
 06. Approximate Location by River Drainage, Distance, and Direction
 07. Where Did Significant Neighboring Groups Live at That Time?
-

items that will be collected on each individual, items that are already known from previous research on approximately 5,000 living and dead Yanomamö from this area.

b. Core areas are an apparent "attraction" for reasons yet to be determined. Three distinct possibilities immediately lend themselves to the possible explanation of why the core areas appear to be desirable to the Yanomamö who seemingly concentrate their movements and activities within them, and attempt to remain in or near them in most cases.

First, they might contain a desirable "mix" of naturally occurring resources and seasonal opportunities to maximize foraging efforts. It is possible that the habits of important game animals, such as peccaries, tapir, large game birds, caiman, and various species of monkeys are correlated with geographical variables.

Second, they might provide the most desirable mix of settlement choices regarding the economics of the foraging aspects of their economy and the possibility of war with neighbors—a topographical mix that optimizes subsistence requirements (acquisition of wild resources) and yet provides easy, labor-efficient, retreat to defensive locations, such as nearby high, relatively inaccessible peaks, should harassment from more powerful groups force them to move their villages and gardens. I know of many communities that have deliberately located their village sites with defense in mind, i.e., their settlement-site choice was largely determined by political factors. Two geographical factors seem to be involved: putting large, difficult-to-cross, rivers between your village and those of your enemies, and locating your village on the peak of a defensible redoubt, such as a high hill or low mountain, but one that has slopes suitable for gardens.

Third, long-term cultivation within a relatively small area leads to the creation of many gardens that contain long-term producing peach-palm trees, a cultigen that yields extremely abundant harvests, especially in February-March.⁸ Thus, a community that has many nearby but abandoned gardens also has an economically important, predictable, defensible, and reliable staple crop at its disposal—if it is located within easy walking distance to them. The further a group moves from these abandoned gardens, the higher is the likelihood that nearby groups will steal the crops when they ripen. The distribution of older peach-palm groves might therefore serve as an attraction to those who earlier planted them and later left them behind as they moved their garden/village sites. I have frequently heard Yanomamö complain that "others" have stolen their peach palm fruits from gardens that are upwards of one-and-a-half to two days' walk away, a bitter discovery they made after specifically travelling to old gardens to harvest their recently-purloined crops.

It is also possible that the availability of some game animals is improved because of the existence of old gardens, i.e., that the mix of fauna adjusts to the human modifications of the landscape produced by gardening. Thus, areas containing many old gardens might also be good hunting areas for some game animals.

The projected research will investigate these possibilities via scan sampling techniques that will quantify economic efforts at various pursuits (trekking, gardening) as well as the quantities of food

⁸ I spotted this village from the air in approximately 1970, when they were located on the Siapa river. Jacques Lizot, a French anthropologist, visited them briefly in 1973 (Lizot, 1974). It is also likely that K. Good visited them in approximately 1980 (Good, 1981).

and other resources obtained by various methods. In addition, extensive botanical and ecological work is planned, work that will lead to fine-grained characterizations of local and regional differences in plant associations and faunal distributions. The latter work will also entail the systematic investigation of plant succession in abandoned gardens of varying stages of forest reclamation. The ages of these gardens will be estimated by using the ages of individuals who are said to have been born in them.

“Cultural” and “Natural” Variables and Possible Correlations

Let me conclude with a brief discussion of how some of the “cultural” and “natural” variables mentioned above might be correlated, using a few examples of what might be adaptive strategies of some groups in or near the Core Areas, especially Core Area A.

One puzzling feature is that a surprisingly large number of current groups that are known to have moved out of Core Area A in the recent past seem to live in temporary village structures: their shabonos are hastily made and roofed with temporary leaves that must be replaced often.⁹ It is almost as though these groups do not plan to remain in their current village structures very long. Groups with temporary shabonos in 1990 included the two Narimöböwei-teri villages, two of the three Konabuma-teri villages, Shokoburuba-teri and Toobatotoi-teri. Others, not actually seen in 1990, might also have temporary shabonos. The Narimöböwei-teri groups recently occupied an area further to the south, on the Siapa River proper, but have recently moved back toward Core Area A and live on the periphery of it. They claim they left their Siapa area because of a war with the Akawaiyoba-teri, a village now in Brazil (as shown on Map 1).

Groups that seem to be more established within Core Area A, such as the Dorita-teri, Sheroana-teri, Hasuböwä-teri, Ashidowä-teri and others, have permanent, well-constructed, and labor-costly shabonos—as though they are confident they can remain for a long time in their sites. I also had the distinct impression that communities with permanent shabonos also had substantially larger gardens, i.e., seem to have a much more conspicuous commitment to horticulture than the groups with more temporary shabonos. It is possible that differences in the degree to which some villages develop political alliances with allies might help account for this pattern if it is indeed demonstrable by measuring gardens: groups with allies must periodically hold elaborate feasts for them, which requires a more garden area to produce the extra food, especially plantains. I have previously argued that the intensity of warfare among some of the “Shamatari” and “Namowei-teri” groups seems to act as a stimulus for alliance building which, in turn, requires larger gardens (Chagnon, 1966; 1968a; 1968b & c; 1974; 1983[1968]).

It is not yet known whether the relatively smaller gardens of some groups, those that seem to be on the “periphery” of Core Area A, has led to a correspondingly higher economic emphasis on collecting and hunting or whether they simply eliminate or curtail feasting and the extra gardening this requires and manage to subsist from much smaller gardens. This will be investigated in the projected research.

One additional possibility is that these “peripheral” groups have a generally much poorer diet than the groups more firmly entrenched in Core Area A and they not only garden less intensely, but they “trek”

⁹ Many peach palm trees also produce smaller, but still significant, crops in the wet season (May/June). resulted in three more deaths and the abduction of 5 young women.

less intensely as well. One gets the distinct impression that groups like the Narimöböwei-teri and Hiomöta-teri are living in constant fear of their more powerful neighbors and seem to be holding out on their hill top redoubts, reluctant to participate in inter-village trading, visiting and feasting. Hiomöta-teri is an interesting case in point. In 1987 they were living on top a fairly high peak when I visited them, having been recently chased there by the two groups to their west, the groups whence they had earlier fissioned. These two groups killed three important men in their village—including the man who was then the headman. They had a very small garden. This move brought them back closer to the Core Area. In 1987 they were on friendly enough terms with some of the larger groups in the Core Area that they were visiting both the Hasuböwä-teri and the Sheroana-teri, villages to which they are not related. They were clearly in need of allies because of their war with Miomaböwei-teri and Dakowä-urihi-teri. In early 1990 (or late 1989), the Sheroana-teri decided to raid them because, as the story goes, they “failed to deliver dogs” they had promised on an earlier trading visit. The attack resulted in three more deaths and the abduction of 5 young women. It is unlikely that the Sheroana-teri would attack a large, powerful group because of their “failure to deliver dogs.” The Sheroana-teri headman, a man who must be close to 60 years old, was wounded on the raid he initiated, but recovered. The Hiomöta-teri were forced to move again, toward the two other groups that were hostile to them—but possibly less hostile.

These somewhat anecdotal incidents suggest that fear of raids from more powerful neighbors affects settlement pattern noticeably in this area and, most likely, the permanency of occupation in particular sites: the “political” aspects of the environment are possibly as important as the purely ecological and economic aspects. It would indeed be ironic if the peripheralized groups like Hiomöta-teri or Narimöböwei-teri have lower amounts of protein intake simply because they are afraid to go hunting, or, have a marginal caloric intake from cultivated foods because they are reluctant to commit themselves to a particular garden location when they might be forced to move by more powerful neighbors!

REFERENCES

Albert, Bruce 1989 “Yanomami “Violence”: Inclusive Fitness or Ethnographer’s Representation?” *Current Anthropology*, Vol. 30, No. 5, pp. 637-40.

Albert, Bruce 1990 “On Yanomami Warfare: Rejoinder,” *Current Anthropology*, Vol. 31, No. 5, pp. 558-63.

Biocca, Ettore 1970 *Yanoáma: The Narrative of a White Girl Kidnapped by Amazonian Indians*. E. P. Dutton. New York.

Chagnon, Napoleon A. 1966 *Yanomamö Warfare, Social Organization and Marriage Alliances*. Ph.D. Thesis. University of Michigan. University Microfilms, Ann Arbor.

Chagnon, Napoleon A. 1968a “The Feast.” *Natural History*, LXXVI: 34-41.

Chagnon, Napoleon A. 1968b “The Culture-Ecology of Shifting (Pioneering) Cultivation Among the Yanomamö Indians.” *Proceedings of the VIII International Congress of Anthropological and Ethnological Sciences*. Vol. 3, pp. 249-55. Tokyo and Kyoto.

Chagnon, Napoleon A. 1968c "Yanomamö Social Organization and Warfare," In: Fried, M., M. Harris and R. Murphy, Eds. *War: The Anthropology of Armed Conflict and Aggression*. Natural History Press. Garden City, N.Y. pp. 109-59.

Chagnon, Napoleon A. 1974 *Studying the Yanomamö*. Holt, Rinehart, & Winston, N.Y.

Chagnon, Napoleon A. 1983[1968] *Yanomamö: The Fierce People*. 3rd Edition. Holt, Rinehart, & Winston, N.Y.

Chagnon, Napoleon A. 1988 "Life Histories, Blood Revenge, and Warfare in a Tribal Population," *Science*, Vol. 239, pp. 985-92.

Chagnon, Napoleon A. 1989 "Response to Ferguson," *American Ethnologist*, Vol. 16, pp. 565-69.

Chagnon, Napoleon A. 1990a "On Yanomamö Violence: Reply to Albert," *Current Anthropology*, Vol. 31, No. 1, pp. 49-53.

Chagnon, Napoleon A. ms. *Yanomamö Settlement Patterns and Population Dynamics*. (In progress)

Chagnon, Napoleon A. 1990b "Reproductive and Somatic Conflicts of Interest in the Genesis of Violence and Warfare Among Tribesmen," In: J. Haas, Ed. *The Anthropology of War*. Cambridge University Press, Cambridge. pp. 77-104.

Chagnon, Napoleon A. and Raymond B. Hames, 1979 "Protein Deficiency and Tribal Warfare in Amazonia: New Data," *Science*, Vol. 203, pp. 910-13.

Chagnon, Napoleon A. and Raymond B. Hames, 1980 "La 'hipótesis proteica' y la adaptación indígena a la cuenca del Amazonas: una revisión crítica de los datos y de la teoría," *Interciencia*, Vol. 5, No. 6, pp. 346-58.

Daly, Martin and Margo Wilson 1988 *Homicide*. Aldine DeGruyter. New York.

Early, John and John Peters 1990 *The Population Dynamics of the Mucajai Yanomama*. Academic Press. New York.

Ferguson, R. Brian 1989 "Do Yanomamö Killers Have More Kids?" *American Ethnologist*, Vol. 16, pp. 564-5.

Good, Kenneth 1981 "Estableciendo los primeros contactos con nuevos grupos Shamatari, Yanomami del sur," *Boletín Indigenista Venezolano*, Tomo XX, pp. 45-52.

Gross, Daniel 1975 "Protein Capture and Cultural Development in the Amazon Basin," *American Anthropologist*, Vol. 77, pp. 526-549.

Harris, Marvin 1974 *Cows, Pigs, Wars and Witches: The Riddles of Culture*. Vintage. New York.

Harris, Marvin 1979 "The Yanomamö and the Causes of War in Band and Village Societies," in M.

Margolies and W. Carter, Eds. *Brazil: Anthropological Perspectives. Essays in Honor of Charles Wagley*. Columbia University Press. New York. pp. 121-32.

Harris, Marvin 1984 "A Cultural Materialist Theory of Band and Village Warfare: The Yanomamö Test," In: B. Ferguson, Ed. *Warfare, Culture and Environment*. Academic Press. Orlando. pp. 111-140.

Knaft, Bruce 1987 "Reconsidering Violence in Simple Human Societies: Homicide Among the Gebusi of New Guinea," *Current Anthropology*, Vol. 28, pp. 457-82.

Lizot, Jacques 1974 "El rio de los periquitos: breve relato de un viaje entre los Yanomami del alto Siapa," *Antropológica*, Vol. 37, pp. 3-23.

Lizot, Jacques 1989 "Sobre la guerra: Una respuesta a N. Chagnon (Science, 1988)," *La Iglesia en Amazonas*, Vol. 44:23-34.

Melancon, Thomas F. 1982 *Marriage and Reproduction Among the Yanomamö Indians of Venezuela*. Ph.D. Thesis. The Pennsylvania State University. University Microfilms, Ann Arbor.

Neel, James V. 1977 "Health and Disease in Unacculturated Amerindian Populations," In: *Health and Disease in Tribal Societies*. CIBA Foundation Symposium No. 49. Amsterdam, North-Holland.

Neel, James V. and Kenneth M. Weiss 1975 "The Genetic Structure of a Tribal Population: the Yanomamö Indians. XII. Biodemographic Studies," *American Journal of Physical Anthropology*, Vol. 42, pp. 25-51.

Neel, James V. and Napoleon A. Chagnon 1968 "The Demography of Two Tribes of Primitive Relatively Unacculturated American Indians," *Proceedings of the National Academy of Sciences*, Vol. 59, pp. 680-89.

Ross, Eric and Jane Bennett Ross 1980 "Amazon Warfare," *Science*, Vol. 207, pp. 590-91.

Sponsel, Leslie 1983 "Yanomama Warfare, Protein Capture, and Cultural Ecology: A Critical Analysis of the Arguments of the Opponents," *Interciencia*, Vol. 8, pp. 204-210.

SATELLITE SPECTRAL DATA AND ARCHAEOLOGICAL RECONNAISSANCE IN WESTERN GREECE

F.A. Cooper*, M.E. Bauer** and B.C. Cullen*,

53-43
201790
P-16

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

ABSTRACT

A Macro-geographical reconnaissance of the Western Peloponnesos adopts spectral signatures taken by Landsat-5 Thematic Mapper as a new instrument of archaeological survey in Greece. Ancient records indicate that indigenous resources contributed to the prosperity of the region. Natural Resources and Ancient, Medieval, and Pre-modern Folklife in the Western Peloponnesos describes the principal lines of research. For a supervised classification of attested ancient resources, a variety of biophysical surface features were pinpointed: stone quarries, coal mines, forests of oak and silver fir, terracotta-producing clay beds, crops, and various wild but exploited shrubs such as flax.

INTRODUCTION

Archaeology and Greece have been inextricably associated ever since the nineteenth-century beginnings of the discipline; what has driven Greek archaeology is the large body of ancient texts with innumerable references to sites and to cultural and natural resources. A good proportion of Greece's wealth of archaeological sites concentrated in the western Peloponnesos with Olympia, home of the Olympic Games, being the pre-eminent example, Figure 1 (an annotated bibliography of the vast literature in Crowther 1985). The geography of this part of Greece comprises a rich variety of natural resources and permits intensive and continuous cultivation. Thus prosperity comes easily when political factors so permit. In politically or climatically oppressive times the nearby and rugged mountain ranges of Arkadia offer protection to a population migrating from the alluvial coastal plains. Isolation and austerity come in exchange (McGrew 1985; Antoniadis-Bibicou 1965; Panayiotopoulos 1985; Sutton 1988; Wagstaff 1982). The western Peloponnesos especially flourished in the middle and late Bronze Ages when the area became as densely populated as it is today (Chadwick 1978). The classical period saw another zenith, from which there was recession under the Romans and Byzantines. With the Slavic invasions of the sixth century A.D. the area slid into complete obscurity (Vyronis 1981; Weithmann 1978) and only emerged from "The Second Dark Ages" some six centuries later, with the conquests of the Franks. The Ottoman Turks gained control in 1460 with regressive consequences (Topping 1972). An economic and social threshold of major consequences was reached with the Greek War of Independence (1821-1830); this period extended through the Second World War and the Greek Civil War, to about 1960. In the 1960's, the

* Program in Classical Civilization, University of Minnesota

** Director Remote Sensing Laboratory, University of Minnesota

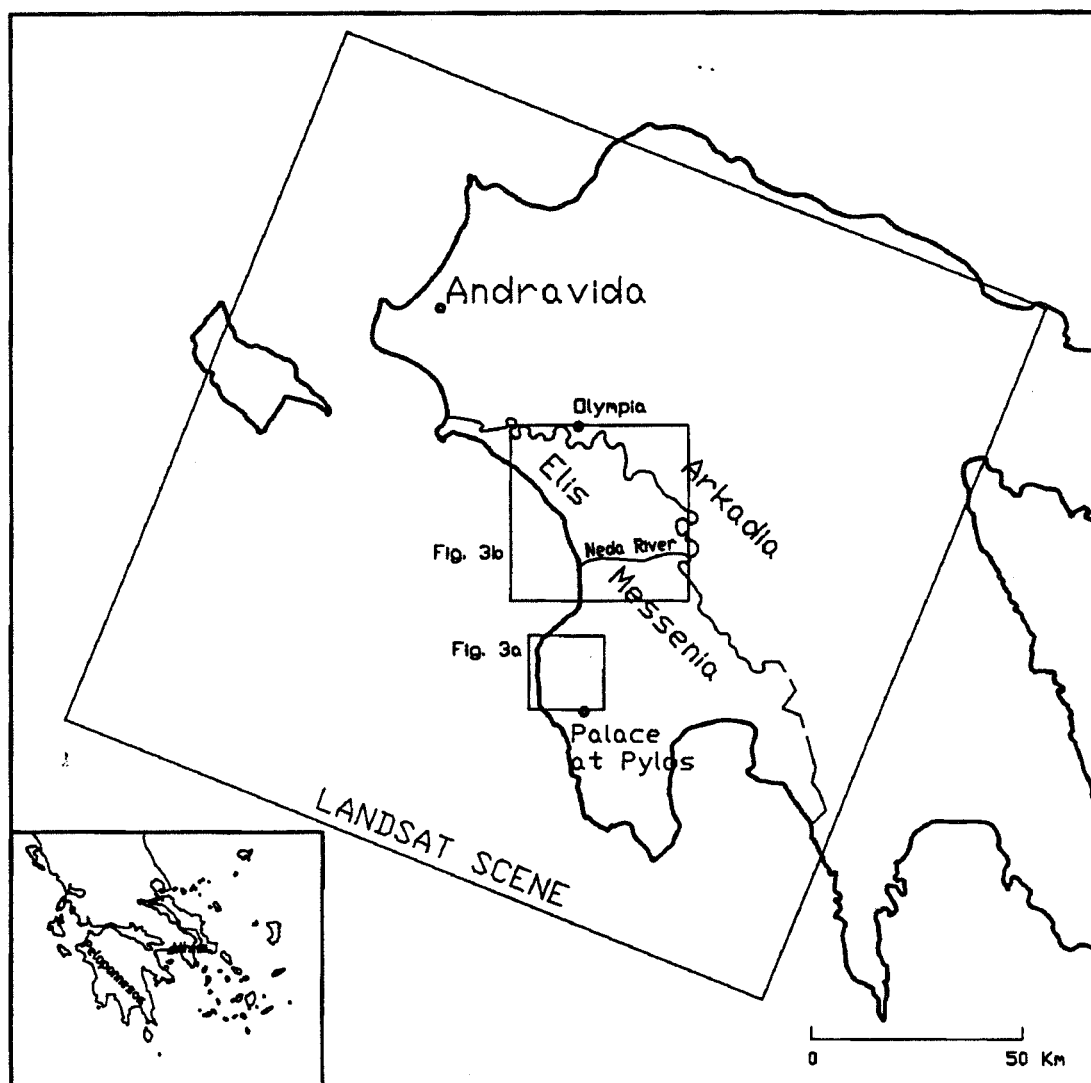


Figure 1. Maps of Greece (inset) and western Peloponnesos.

folklife in the western Peloponnesos abruptly changed from traditional methods of farming to those of the industrialized world; the transformation continues to this day (McGrew 1985; Van Andel and Sutton 1987). Literacy and inscribed testimonia comes and goes along with the economic and social fluctuations.

In the first century A.D. Strabo wrote *The Geography*, a work largely devoted to a geographical description of Greece (Baladié 1980). In the mid-second century A.D., Pausanias wrote a *Description of Greece* which is, in effect, a travel guide to the country. One third of this book is devoted to the West and South Peloponnesos (Frazer 1898). Archaeologists working in Greece have continuously used the testimonia to identify sites or to reconstruct historical events related to sites. The Bronze Age palace at Pylos (1350-1300 B.C.) and the Frankish capital of Andravida (1250-1450 A.D.) provide two examples of sites known by their original names only through the study of ancient written sources.

The University of Minnesota embarks on two major archaeological enterprises in the western Peloponnesos with the aforementioned Pylos and Andravida the foci of archaeological research. Several pilot projects envisioned for the coming seasons represent cardinal steps leading towards

future excavations: 1) an intensive archaeological survey of the vicinity of Andravida (co-director, Professor Joseph Alcherms); and 2) the excavation of back-filled trenches to be followed by a logistical and a topographic survey of the Pylos area. This project at Pylos will be undertaken by a multi-university collaboration including the Universities of Illinois at Chicago (J. Davis); Wisconsin (J. Bennet); Texas (C. Shelmerdine and T. Palaima); and Minnesota (F. Cooper, M. Nelson). These projects entail an examination of the full landscape surrounding each site, and include a concentrated investigation of natural and cultural resources. Towards such an understanding, we have begun to correlate ancient written sources with satellite remote sensing. "The first step in predicting cultural resources is to define the resource one is interested in" (Ebert and Lyons 1980: 126). A few words about archaeological surveys should preface the discussion of satellite remote sensing.

In recent years, the intensive regional survey aimed at identifying historical sites and cultural resources has become a familiar and widespread undertaking in Greece (Van Andel and Runnels, 1987; Keller and Rupp 1983; Cherry *et al* 1988; Wright 1990). In this respect and others, the *Minnesota Messenia Expedition: Reconstruction of a Bronze Age Regional Environment* was a pioneer (McDonald and Rapp: 1972).

Traditional surface survey and aerial photographs, however, have limitations when it comes to the prospection of natural and cultural features. For instance in the early 1970's The Minnesota Messenia Expedition thoroughly canvassed the southwestern Peloponnesos for sites from the Neolithic through Roman periods. In the same time period, Cooper discovered by chance the archaic and classical ruins of Prasadakion hidden under dense brush at the crown of a hill, and the ruins of another classical temple at Perivolia. The Minnesota Expedition had overlooked both sites. Under ordinary circumstances, these ruins would still be undetected, since intensive archaeological survey typically focuses on the surface of the ground, noting especially pottery fragments. This approach, while valuable, easily bypasses ruins rendered nearly invisible and inaccessible by thickets of bushes (Sever 1983: 3). Since satellite remote sensing makes it possible to survey a sizable territory with great comprehensiveness, accuracy and speed, this tool will help reshape traditional survey methods and goals. Our prior exposure to remote sensing took the form of low-altitude balloon photography. In 1978, a collaboration was formed between Elie and Will Myers and Cooper for the aerial reconnaissance of ancient Phigaleia (Cooper and Myers 1981: 145-159; Myers, 1978). The Phigaleia project was part of a wider effort to locate quarries of the marble that went into works of sculpture and architecture found in the vicinity, including those at Olympia (Cooper 1988, 1986). At that time, Cooper acquired a set of Landsat 1 composite images. In the 1970's, however, the analytical and statistical manipulation and interpretation of satellite spectral data required main frame computers and software written by a dedicated programming staff. Even so, the resultant low-altitude balloon photographs, Figure 5, as well as the multispectral scanner (MSS) composite images, figure 2, played an important role in our recent digital image interpretation of many training sites including Phigaleia.

In the 1980s, when microcomputers and commercial software became available, diverse avenues involving remote sensing research emerged (Jensen 1987: 50-61; Sever 1983: 2; Sever and Wiseman 1985: 11; Custer *et al* 1986: 583). At the University of Minnesota, several faculty members with research interests in agriculture, forestry and archaeology have formed a joint project: Professors Joseph Alcherms and Cooper (Classical Studies) collaborate with Professor Marvin Bauer, director of the Remote Sensing Laboratory in the Department of Forest Resources, on a spectral reconnaissance of the natural and cultural resources of the western Peloponnesos (Cullen, Cooper

and Bauer, n.d.; Baker and Gumerman 1981: 15; Brown and Ebert 1978; Ebert 1978).

The introduction of remote sensing to the traditional toolbox of archaeology, on the other hand, "provides us with much more complete information on...physiography than could ever be obtained by traditional ground survey methods" (Lyons *et al*, 1976: 127). In fact, the use of spectral data in prospecting for cultural resources is the most valuable technique in ethnological, ecological, geological, hydrological and archaeological studies today (Camilli and Cordelli 1983: 77; Tartaglia 1977: 48; Schalk and Lyons 1976; Kruckman 1987; Marmelstein 1977; Bellerby *et al* 1990). In addition to such hidden architectural remains, a rich and varied fabric of cultural entities and natural resources embraces the western Peloponnesos. A comprehensive inventory of natural and cultural resources, therefore, as they were exploited in antiquity, would require endless wanderings throughout the Greek landscape, and for an eventual discovery would be little more than a product of luck. Biophysical signatures extracted from satellite spectral data offer a method which greatly facilitates prospection for ancient cultural resources and improves considerably the results of prospection. (Sheets and Sever 1988: 35; Szakiolda 1988; Custer, Eveleigh, Klemas, and Wells 1986). The data are collected by a remote sensing system that records electromagnetic radiation, or, EMR. The Thematic Mapper of Landsat 5 and the French SPOT are the newest and most valuable of remote sensing systems.

Our purpose in incorporating remote sensing into our archaeological research is two-fold. Primarily, we are interested in the macroview of an archaeological site. This involves the identification and analysis of the natural resources found in the surrounding area. We will then be able to theorize about migration, colonization, and economy.

Of critical importance to our archaeological research is a quantity of clay tablets discovered at the Bronze Age site of Pylos inscribed with the Linear B syllabary. When Linear B was deciphered in 1953, the Pylos tablets were found to be essentially administrative records, itemizing resources such as livestock and crops (Chadwick 1976: 102-134; 1987). These inventories show that exploitation of natural resources lay behind the impressive wealth accumulated by this Bronze Age center. Outside the Peloponnesos, for example in the Palace at Knossos (Crete), Linear B tablets were discovered that show a count of more than 100,000 sheep (Killen 1964; 1966; 1984: 49-53; Chadwick 1973: 133, 413). For a census of sheep and goats, the Pylos tablets are much less complete than are those of Knossos; nonetheless, there is good reason to imagine that the numbers of sheep at Pylos were comparable (Chadwick 1973: 197-199; Hooker 1980: 41).

Flax also plays a central role in the textile industry at Pylos, far more so than at any other known Mycenaean center. In the N-series of Pylos tablets the ideogram SA appears frequently and in reference to the raw fibers, to the thread and to the cloth made from flax and perhaps esparto (Killen 1984: 53-55). The quantities of harvested flax are impressive by any standard: a single village contributed approximately three tons, while the average amounted to nearly a ton per contributing settlement (Chadwick 1976: 153-154).

The tablets attest groups of women and children (over 600 in the Pylos Aa tablets; Hooker 1980: 101-105) who carded, spun, wove, decorated and sewed the raw fibers of wool and flax into textiles; indeed, the female textile workers of flax were accorded the name *ri-ne-ja* from which derives the word *linen-[weavers]* (Killen 1984: 52-53; Chadwick 1973: 63, 131-132, 413). A cottage industry of linen-making probably continued without interruption until the 1950's, when commercial

ORIGINAL PAGE
COLOR PHOTOGRAPH



Figure 2. Landsat 1 Multispectral Scanner (MSS) color composite of the Western Peloponnese, Greece. Taken 8 September 1972.

textiles displace the handmade linens (Griebel n.d.).

Large amounts of wheat are recorded for Pylos (E-tablets); here the tablets refer to land holdings where the sizes of plots are given in terms of yield. Locations of the fields are not given, with one exception: a place called *Pa-ki-ja-ne* in Pylos tablet En 609 (Hooker 1980: 133). Its area included the Palace, and was located by Chadwick (1972:102, 105; 1973: 139; 1976:45) in the vicinity of the modern town of Gargalionoi, Figures 1 and 3a.

The administration at Pylos oversaw the manufacture of quantities of perfumed oil, requiring large quantities of raw materials and scents such as rose petals where approximately 1000 roses are required to produce 7.4 liters of (Shelmerdine 1984: 82; 1985). Speciality woods named in the "chariot" and "furniture" tablets include elm, willow, ebony (?), yew, boxwood and cypress, all trees indigenous to this part of Greece. Tablet Vn 10 names the settlement *Ro-u-so*; it lay towards the interior, probably within Arkadia, Figure 1, and had woodcutters as well as large numbers of sheep (Chadwick 1972: 108; 1973: 123, 350; 1976: 40; Hooker: 84). We return to this point below.

The purpose of the preceding account is to provide a general idea of the kinds and quantities of natural resources exploited by the administrative center at Pylos. This synopsis does not pretend at completeness nor is it meant as a learned interpretation of the Linear B tablets. We wish only to emphasize that these documents encourage the application of phytoarchaeology. Phytoarchaeology may be defined as the analysis of relationships between vegetation and archaeology (Brooks and Johannes 1990: 9). This new branch of archaeology, derived from the fields of geobotany and geochemistry, is intended to detect "subsurface phenomena through analysis of surface vegetation." Scientific research has shown that "underlying geological materials appear to have a significant effect on the incumbent vegetation" (Brooks 1972: 9, 57-58). Biogeochemical studies of vegetation over ancient and medieval sites has shown that human activity can modify soils in different ways, and that this is detectable by analysis of plant growth. Ancient mines and mining operations alter the phytotoxicity of the surface soil (Brooks and Johannes 1990: 66-74). Or, calciphilous plants (limestone flora) are good indicators of limestone areas, whether they be built fortification enceintes, citadels or a midden of shellfish (Brooks 1983). As illustrated below, the supervised classification of limestone walls, both those which are visible and those totally obscured by heavy overgrowth, as at Prasadakion, Figure 3b, represents just such an application of phytoarchaeology.

Three classes of satellite spectral variables are subject to measurement and evaluation. The first class of data can provide basic biophysical information directly, without need of supplemental or subordinate data (Jensen, 1986, pp.2-3); two examples are the determination of x, y, and z coordi-

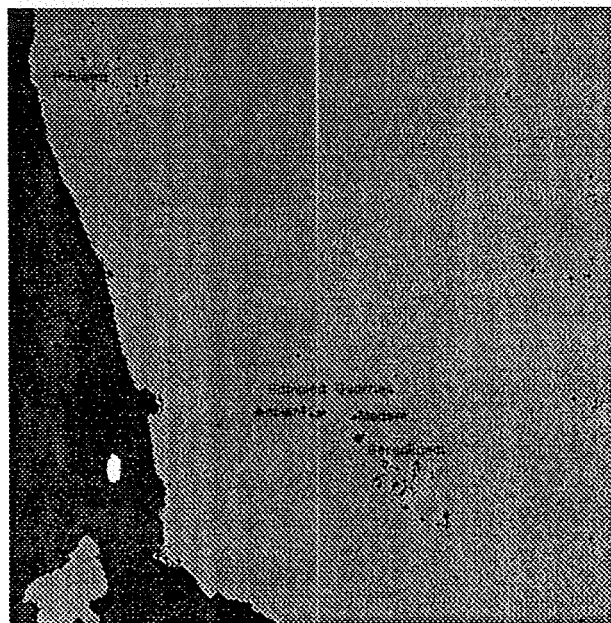


Figure 3a. Enhanced spectral image of classified quarries.

nates and the measurement of vegetation biomass. The second class of variables is hybrid, that is to say, a compound of biophysical variables that leads to an assessment of object color, location, temperature, etc. Land cover mapping is achieved by this means. (Jensen, 1986, pp.2-3). The third class of spectral variables is interpretive, and is developed by inferences based on the other two classes of variables: examples include applications of phytoarchaeology, mentioned above (Campbell 1987: 444-449) and geobotany (Sever and Wiseman 1984: 57-83). There may also be ecological and social considerations, for example, the observation that forests of Kerm and Hungarian oak could support large herds of sheep fed by acorns (cf. Lyons and Avery, 1977; Baker and Gumermann, 1981; Kruckman, 1987).

In modern studies it is claimed that forty percent of the province of Messenia is arable, as opposed to the national average of twenty-eight percent (McDonald and Rapp 1972; Chadwick 1978: 48). There has been only slight interest in the history of land use in Messenia and ours is the first attempt to correlate the contents of these documents with the natural resources observed in this locality. For instance, Bronze Age scholars have surmised that the grazing lands for the aforementioned herds of sheep were either the coastal plains surrounding the Palace, or an extensive river basin 30 Kilometers to the north (Chadwick 1976); yet little more than mesquite thrives in these two locations which, currently can support no more than 50 sheep per shepherd. We believe that the ancient grazing lands were the oak forests that lie to the northeast of Pylos and spread across a plateau atop the mountain chain that rises sharply from the rolling coastal plains. The ribbon of bright red, running northwest to southeast in the bottom center of Figure 2 is a dense tract of oak which falls along the southwest edge of a precipitous ridge near Pylos. The evidence confirming that this region was an ancient grazing area appears in the writings of ancient authors who noted that sheep fed in oak forests on the fallen acorns (Philostratus VA 8.7.12). This grazing method continues today.

Classicists, archaeologists, and ecologists typically take the position that Greece was deforested in antiquity (Meiggs 1982; Van Andel and Runnels 1987). These scholars base their arguments for pre-modern deforestation on little more than circumstantial evidence. Numerous references to forests and forestry in ancient sources support our hypothesis that Greece was not deforested in antiquity (Cooper n.d.); this suggestion finds independent confirmation in classified spectral data which highlight particular topographic features of the modern Greek landscape, such as the large tracts of oak forests discussed above. An even more striking expanse of oak lies 100 kilometers northeast of Pylos, east of the lake near the center of Figure 2, where flocks of between 300 and 500 sheep per shepherd are pastured.

The fallacy concerning the decimation of oak trees in antiquity applies to silver fir as well. Ancient authors, among them the fourth-century B.C. natural scientist Theophrastos and the fifth-century B.C. historian Thucydides refer to tracts of silver fir in Arkadia, the mountainous, land-locked territory of the central Peloponnesos which occupies the entire central portion of our satellite

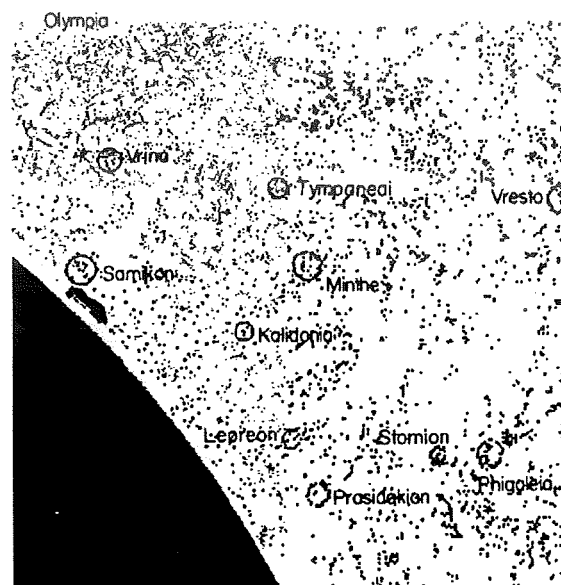


Figure 3b. Enhanced spectral image of classified quarries

scene, figures 1 and 2. Silver fir was highly prized as an essential material in the construction of ships for the various military and mercantile fleets of the classical and medieval dominions. Until now, scholars supposed that Italy and Macedonia were the sole sources of this timber; however, satellite spectral analysis reveals vast tracts of silver fir covering Mount Eurymanthos in Arkadia. The large, deep-red patches at the right center of the scene in Figure 2 represent this colossal forest.

When we commenced our macro-geographic survey of the indigenous resources of the western Peloponnesos last summer, the almost-forgotten Landsat 1 MSS images of 1972 became valuable assets. This set consists of two black and white, one enhanced for vegetation cover, the other for rock/soil characteristics. The set also includes one MSS color composite, Figure 2. These photograph-like images were used for guidance during field sampling, along with a large collection of geological, topographical, statistical, and cultural maps as well as stereoscopic aerial photographs. In our reconnaissance of last summer, we employed a number of metrological and cartographical short cuts for plotting with reasonable accuracy our pixelled ground cover features, and for placing ground cover features recorded during ground truth reconnaissance onto working plans. We sought geological features and homogeneous vegetation canopies larger in area than ca. 90 m. on a side; that is, larger than a grid of three by three Landsat TM pixels. In this way, the central pixel falls within the sampled, ground cover and is therefore a "pure" pixel, while the pixels at the perimeter of the array may be "mixed" pixels. The sampled field size should approach 240 meters by 240 meters for optimal classification accuracy (Jensen 1986: 32; Cullen, Cooper and Bauer, n.d.). In most cases, we maintained this field size, but some classes of ground cover, such as orchards and wild shrubs, seldom reach these dimensions (Morain and Bridge 1978). The pinpointing of sampled biophysical components was done on Greek maps which have been reproduced at a scale of 1:50,000. This scale permits the location of specific examples of ground cover to the nearest second of a degree of latitude and longitude. Multiple samples of each class of ground cover were also located, ensuring the consistency of individual spectral signatures. A selection of features were photographed using infrared films, both color reversal and black and white, which provided further visual guides. Accuracy in plotting sampled features was achieved by triangulation using reverse compass azimuths from landmarks such as mountain peaks, road intersections and villages. In addition, odometer readings, adjusted for road curves, verified our 'pixelling' position with respect to nearby villages or some other easily detected landmark (Cullen, Cooper and Bauer, n.d.).

With this method, we managed to pinpoint a full range of biophysical components including modern and ancient quarries of limestone, marble, gypsum, and flint, as well as newly discovered coal. We also located multiple samples of clay: both exploited claybeds used for the manufacture of terracotta products such as pottery, bricks, and roof tiles, as well as ordinary claybeds. Cultivated crops were targeted as were cultivated and wild plants and flowers (Sfikas 1984) such as flax and esparto. These plants are cited in the Pylos Linear B texts, and their fibers were commonly used until modern times to manufacture rope as well as textiles.

We acquired a full Thematic Mapper Scene from EROS (Landsat 5, path 18, row 34, obtained 17 June 1987. Centerpoint, N37°28'00" E21°37'00"), which by good fortune turned out to be cloudless and flawless. Meantime, we are familiarizing ourselves with the ERDAS image processing system, its procedures and commands. At present, our primary concern involves the supervised training and classification of those types of ground cover that we pinpointed during last season's geographical survey.

The ellipse scatterplot of spectral data is one of several graphic options available on the ERDAS system for the evaluation of training signatures. The scatterplot portion of the chart appears as a puddle of white points that graphically represents a cross-sampling of spectral values as they appear in two user-specified spectral bands. Each colored ellipse represents the biophysical signature of a single training sample. The greater the overlap of ellipses, the more homogeneous the values of the training pixels. For example, Figure 4a is an ellipse scatterplot which presents an evaluation of sampled quarries, while Figure 4b provides that of citadels (and enceintes). The ellipses represent

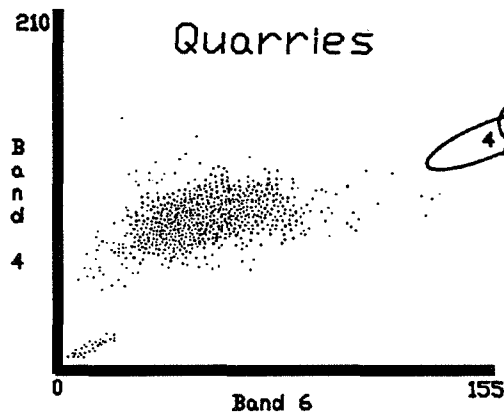


Figure 4a. Enhanced spectral image of classified quarries.

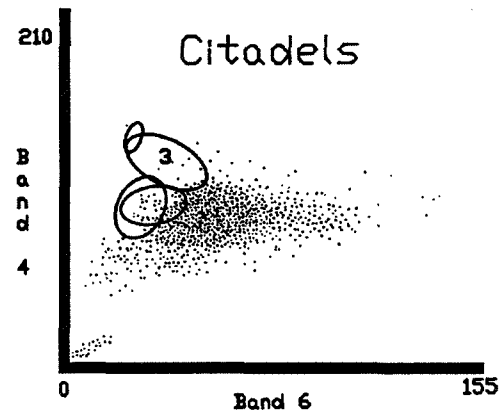


Figure 4b. Enhanced spectral image of classified citadels and forts.

the supervised training signatures of pinpointed quarries and citadels. Notice how the ellipses cluster together and, more importantly, how they stand apart from the scatterplot in the upper right-hand portion, of which a high percentage of points must represent the extensive areas of exposed limestone bedrock in our TM scene.

Our first classifications have produced exciting results. The signature statistics for our test classifications of quarries and citadels amply testify to the potential of spectral analysis for prospection of archaeological features. Table 1 presents statistics of four quarry signatures after they have been subjected to a maximum likelihood classification. Out of more than 13 million pixels, only a total of 857 pixels are assessed as potential quarries. Positions of the pixels classified as quarries in the vicinity of Gargalianoi appear in Figure 3a as an overlay of blackened polygons superimposed on top of a grey-scale of our TM image. At the lower right appear three especially vivid spots which represent two of our

Table 1. Supervised Classification of Quarries

Class #	Name of Site	# Points Found	Percent of Total Points
1	quarry-Xerohorion	42	0.00%
2	quarry-Gargolianoi 1	5	0.00%
3	quarry-Gargolianoi 2	5	0.00%
4	quarry-Gargolianoi 3	805	0.01%
0	everything else	13,280,803	99.99%

Maximum Likelihood Classifier, Standard Deviation=1.5.

quarry training sites. We are optimistic that spectral interpretation aimed at the classification of unknown pixels will guide us to additional modern quarries, as well as to a number of uncharted ancient ones in our TM scene. Especially promising are the possible quarries which line the coast at or near natural harbors. Ancient quarries frequently were located in such positions, which offered the greatest convenience: the easy transport of multiple-ton stone blocks to water's edge and shipment by sea to various destinations (Cooper 1988).

After some experimentation, we discovered a means of classifying citadels, fortification walls, and other ruins obscured by vegetation. A chief reason for this exercise was to determine whether archaeological ruins that are invisible due to an overgrowth of vegetation could be detected by the spectral analysis of satellite data. As noted earlier, an intensive archaeological survey normally fails to detect these cultural features. The Myers 1978 low-altitude balloon photographs of the Phigaleia fortifications formed a basis for our present analysis (Myers, 1978; Cooper and Myers 1981: 145-159). These dressed stone walls stand as high as 3-4 meters, but are flanked by a dense growth of prickly oak, a calciphilous plant (Brooks 1983), as seen in the aerial photograph in Figure 5. Similar conditions obtain at the fortifications of Kato Samikon, Lepreon, the walls of unknown date at Kalidona, and the aforementioned ruined temples of Perivolia and Prasadakion, as well as the Byzantine chapel at Anilio.

Using known citadels as guides, we trained pixels of overgrown walls that form visible lines around the circumference of fortified cities. The ruins at Tympaneai just east of Mt. Smerna, which we had not managed to locate visually on the computer screen, conspicuously appeared after classification, Figure 3b. We also noticed a circuit of bright red pixels surrounding the town of Vrina as seen in Figure 3b. Fortification walls have never been noticed there, perhaps because they are overgrown with vegetation. Table 2 lists the signature statistics for the citadel classification. The results are as encouraging as those of the quarry classification. Discrimination from other classes is high with a suitable 8% of the pixels in the scene having spectral characteristics of an archaeological ruin. We expect to filter at least half of this percentage in a GIS analysis of shapes and textures. In addition, electronic aids such as density slicing instruments and edge enhancing techniques will further aid in "achieving the desired result of site discovery and evaluation or environmental analysis" (Lyons and Avery 1977: 54).



Figure 5. Phigaleia fortifications, detail.
Low-altitude balloon photograph
by E. and W. Myers, 1978.

Our preliminary classification scheme will serve as a guide for the archaeological prospection of

fortified sites in the coming seasons. We assume that hundreds of hilltop fortifications have gone undetected, in large part because the terrain over which they are scattered is difficult and often impassable. The fortifications that have been recorded vary considerably in size, layout and purpose. Isolated structures were perhaps lookout towers, while walled tower complexes served for reconnaissance and defense.

A comprehensive mapping of towers and tower-complexes will make it possible to appreciate and to analyze the principles that governed the development of ancient and medieval defensive networks. The case of the citadels at Smerna and Vrina in the rugged mountain range just south of Olympia (Figure 3b) illustrate the advantages of prospection by satellite spectral analysis. The *castello* of Smerna is attested in a list of barons

who held castles in fief from Joanna of Anjou, Queen of Naples (Bon 1969: 377, 689). Luttrell (1958: 355) showed that this list was compiled in 1377, and Bon convincingly identified Smerna with a site which Greek literary sources call Araklovon, mentioned already in several texts that describe the events of the Frankish conquest of 1205 (Bon 1969: 370). A Greek garrison stationed here offered fierce resistance to the advancing Franks, thanks to the impregnable position of the *castello* and the determination of the Greek leader, Doxopatres Voutsaras. The list of 1377 is the oldest known member of a series of fourteenth and fifteenth century administrative documents which include the *castello*. One of these, a feudal list dated to 1391, provides evidence for the population of the settlement whose defense depended on the *castello*: with 100 households, Smerna was a sizable village (Bon 1969: 692). Lists culled from late fifteenth-century Venetian annals point to the passage of Smerna from western to Turkish control: the *castello* was in Venetian hands in 1463, but by September 1467, it had fallen to the Turks (Bon 1969: Appendix I, 693-694).

About five kilometers northeast of this well-documented medieval settlement is the village of Vrina. Today it comprises about eighty dwellings, many abandoned and in danger of collapse. Two Venetian censuses (conducted in 1689 and 1700) attest the existence of Vrina, a cluster of fewer than thirty houses in seventeenth century (Panayiotopoulos 1985: 228, 253). Unlikely is it that this smaller village was founded under Turkish rule; more likely, Vrina existed under the Franks as a dependency of Smerna. On the other hand, Vrina is surrounded by a configuration of pixels classified by the "citadel" training signature. The evidence of this spectral analysis suggests that Vrina has an enclosing stone wall. When the site was visited in the summer of 1990, no fortifications were noticed, presumably because they are obscured by dense vegetation.

The pixels in figures 3a and 3b were clumped and color-coded as black. Still, in figure 3a it is

Table 2. Supervised Classification of Citadels and Fortifications

Class #	Name of Site	# Points Found	Percent of Total Points
1	Citadel-Phigaleia	295,117	2.22%
2	Citadel-Samikon	264,574	1.99%
3	Citadel-Vrina	176,064	1.33%
4	Citadel-Kalydona	256,230	1.93%
5	Spring-Phigaleia	783	0.01%
6	Citadel-Lepreon	34,693	0.26%
0	Everything else	12,254,199	92.26%

Maximum Likelihood Classifier, Standard Deviation=1.5.

possible to see patterns of pixels that follow the circular course typical of an ordinary defense wall. In the upper right area of Figure 3b, there appears an identical configuration. Only in a ground truth reconnaissance can we ascertain whether these walls exist and whether they are the work of ancient, medieval or Turkish builders.

The assessment of this network of walled settlements and defensive towers can be coordinated with the analysis of other systems created or adapted in the Middle Ages and early modern period. A better understanding of the relation between these defenses and the medieval road systems that criss-crossed the region will shed light on commercial patterns and contacts among the Franks of the Morea, their Greek rivals elsewhere in the Peloponnesos, the Italian maritime powers with interests in coastal development, and later, the invading Turks.

The physical remains of several hydraulic systems which may have developed from medieval aqueducts are preserved in the area, and image enhancement of our TM scene by hydrological rationing reveals the possible existence of irrigation channels in the vicinity of Andravida. Dates for the system of waterworks might be obtained by analysis of the rate of accretion of calcium deposits encrusting the surviving aqueducts. Also the examination of hedgerows that cover the walls of aqueducts and defense works may be of use in establishing a chronology for these constructions. In his study of hedgerow growth, Hooper argued that new species combine with the older components at the rate of one new species about every century (Pollard, Hooper and Moore 1974; Rackham 1986: 194-204). Whatever their period, these hydraulic systems are fundamental evidence for the evaluation of the agriculture of that period. If they prove to be medieval, they broaden our picture of the territorial development undertaken by the western invaders and deepen our understanding of the attractions that this land held for them. Our preliminary investigation warrants the hypothesis that the Franks were interested in the abundant raw materials suitable for the production of cloth: wool, flax for linen, esparto for rope, cotton, and mulberry trees for silk worms.

The current phase of research continues with our classification scheme: the processing and analysis of data and the extraction of spectral signatures from our pinpointed resources. We plan to compile a set of training signatures appropriate to phytoarchaeological and spectral prospection in the larger regions surrounding our target sites, Pylos and Andravida. These signatures, will then serve to supplement the NASA Reference Publication *Spectral Reflectances of Natural Targets for Use in Remote Sensing Studies* (Bowker *et al* 1985). This will simplify the prospection of ancient sites and of additional resources in our archaeological zone and prepare us for another season in Greece.

ACKNOWLEDGMENTS.

The cheerful goodwill, the protracted and very real guidance of Steve Lime and John Ladwig at the Remote Sensing Laboratory of the University of Minnesota allowed for this report on spectral analysis to come into being. To them we owe special thanks. We also are indebted to the valuable participation of Tom Asher during the summer of 1990 and to the assistance of Professor Joseph Alcherms, Pieter Broucke and Helen Griebel. Funds for the project have come from the University of Minnesota Graduate School Grants-in-Aid, the Undergraduate Research Opportunities Program and a College of Liberal Arts Distinguished Teachers Award.

REFERENCES

- Antoniades-Bibicou H. 1965. "Villages désertes en Grèce: un bilan provisoire" in Villages désertes et histoire économique. XIe-XVIIIe siècles (École Pratique des Hautes Études, Paris, pp. 343-417.
- Baker, C. and G.J. Gumermann, 1981. "Remote Sensing: Archaeological Applications of Remote Sensing in the North Central Lowlands". In T.R. Lyons (editor), Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers. Supplement 6. Washington D.C., 9-21.
- Baladié, R. 1980. Le Péloponnèse de Strabon: étude de géographie historique. Paris.
- Bellerby, T.J., M. Noel, and K. Branigan, 1990. "A Thermal Method for Archaeological Prospection: Preliminary Investigations", Archaeometry 32(2):191-203.
- Bon, A. 1969. La Morée Franque: Recherches historiques, topographiques et archéologiques sur la principauté d'Achaïe, Paris.
- Bowker, D.E., R. Davis, D. Myrick, K. Shey, and W. Jones, 1985. Spectral Reflectances of Natural Targets for Use in Remote Sensing Studies. Washington D.C.: NASA.
- Brooks, R. R. 1972. Geobotany and Biogeochemistry in Mineral Exploration, New York.
- Brooks, R.R. 1983. Biological Methods of Prospecting for Minerals, New York.
- Brooks, R.R. and D. Johannes, 1990. Phytoarchaeology, (Historical, Ethno- & Economic Botany Series), 3, Portland.
- Brown, G.N and Ebert, 1978. "Ecological Mapping for Purposes of Sample Stratification in Large-Scale Cultural Resources Assessment" in Remote Sensing and Non-Destructive Archaeology, Washington, pp. 53-63.
- Camilli, E.L. and L.S. Cordelli, 1983. "Remote Sensing: Applications to Cultural Resources in South Western North America", B.L. Daniels (editor). In T.R. Lyons (editor), Remote Sensing: A Handbook for Archaeologists and Cultural Resource Managers. Supplement 8. Washington D.C., 77-83.
- Campbell, J.B., 1987. Introduction to Remote Sensing. New York: Guilford Press.
- Chadwick, A. J. 1987. "A Computer Simulation of Mycenaean Settlement" in Simulation Studies in Archaeology ed. Ian Hodder, Cambridge, pp. 47-57.
- Chadwick, J. 1972. "The Mycenaean Documents" in The Minnesota Messenia Expedition: Reconstructing a Bronze Age Regional Environment, eds. W. McDonald and G. Rapp, Minneapolis, pp. 100-116.
- Chadwick, J. 1973. Documents in Mycenaean Greek, 2, Cambridge.

Chadwick, J. 1976. The Mycenaean World, Cambridge.

Chadwick, J. 1987. Linear B and Related Scripts. (Reading the Past), 1, Berkeley.

Cherry, J.F. J. L. Davis, A Demitrack, E. Mantzouri, T.F. Strasser and T. Talalay. 1988. "Archaeological Survey in Artifact-Rich Landscape: A Middle Neolithic Example from Nemea, Greece," AJA 92, pp. 159-176.

Cooper, F.A. and W. Myers, 1981. "Reconnaissance of a Greek Mountain City", Journal of Field Archaeology 8:123-134.

Cooper, F.A., 1986. "The Stones of Bassai". In Science in Archaeology, London, 21-34.

Cooper, F.A., 1988. "The Quarries of Mount Taygetos in the Peloponnesos". In N. Herz and M. Waelkens (editors), Classical Marble Geochemistry, Technology, Trade. Dardrecht, 65-76.

Cooper, F.A. .n.d. "Timber and the Economy of Ancient Arkadia," in preparation.

Crowther, N.B. 1985. "Studies in Greek Athletics," Classical World 78 and 79.

Cullen, B. F. Cooper and M. Bauer, n.d.. Satellite Imaging and Prospecting for Quarries and Natural Resources. ("Ancient Building and Statuary Stones: Quarrying and Provenance", in Acta Archaeologica Lovaniensia

Custer, J.F., T. Eveleigh, V. Klemas, and I. Wells, 1986. "Application of Landsat Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain", American Antiquity 51(3):573-588.

Ebert, J.I. and T.R. Lyons, 1977. "Remote Sensing Within an Archeological Research Framework: Methods, Economics, and Theory". In Remote Sensing Techniques In Archeology, Washington D.C., 169-192.

Ebert, J.I. and T. Lyons 1980. "Prehistoric Irrigation Canals Identified From Skylab III and Landsat Imagery in Phoenix, Arizona" in Cultural Resources Remote Sensing, Eds. Lyons and T.R. Mathien Washington, D.C., pp. 209-227.

Frazer, J. 1898. Pausanias's Description of Greece, London.

Griebel, H.B. n.d.. "Sparto, A Greek Textile Plant," in preparation.

Gumerman, G.J. and L.D. Kruckman, 1977. "The Unrealized Potential of Remote Sensing in Archaeology". In Aerial Remote Sensing Techniques In Archeology. Washington D.C., 15-33.

Hooker, J.T. 1980. Linear B An Introduction, Bristol.

Jensen, J.R., 1986. Introductory Digital Image Processing: A Remote Sensing Perspective. Englewood Cliffs.

Keller D. R. and D. W. Rupp, eds., Archaeological Survey in the Mediterranean Area. (BAR International, 155), Oxford.

Killen, J. T. 1984. "The Textile Industries at Pylos and Knossos" in Pylos Comes Alive eds. T. G. Palaima and C. W. Shelmerdine, New York, pp. 49-63.

Killen, J.T. 1966. "The Knossos Lc(Cloth) Tablets," BICS 13, pp. 105-109.

Killen, J.T. 1964. "The Wool Industry of Crete in the Late Bronze Age," BSA 59, pp. 1-15.

Kruckman, L., 1987. "The Role of Remote Sensing in Ethnohistorical Research," Journal of Field Archaeology 14:343-351.

Luttrell, A. T. 1958. "A Fourteenth Century List of the Barons of Achaea (1377?)," Byzantinische Zeitschrift 51, pp. 355-356.

Lyons, T.R. 1981. "Remote Sensing: Multispectral Analyses of Cultural Resources: Chaco Canyon and Bandelier National Mo.," (Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers, ed., T.R. Lyons), 5, US Dept of Inter pp. 43-59.

Lyons, T.R. and T.E. Avery, eds. 1977. Remote Sensing: A Handbook for Archaeologists and Cultural Resource Managers. Washington, D.C.

Lyons, T.R., R.K. Hitchcock, and B.G. Bouls, 1976. "The KinBineola Irrigation Study: An Experiment in the Use of Aerial Remote Sensing Techniques in Archaeology." In Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archaeological Exploration. Washington D.C., 11.

Marmelstein, A.D. 1977. "Aerial Remote Sensing in Marine Archaeology" in Aerial Remote Sensing Techniques In Archeology. U.S. Department of the Interior, pp. 103-109.

McDonald, W. and G. Rapp, 1972. The Minnesota Messenia Expedition: Reconstructing a Bronze Age Regional Environment. Minneapolis.

McGrew, W. W. 1985. Land and Revolution in Modern Greece, 1800-1881, Kent.

Meiggs, R. 1982. Trees and timber in the Ancient Mediterranean World, Oxford.

Morain, S., G. Nelson, M. White, and A. Komarek, 1981. "Remote Detection of Prehistoric Sites in Bandelier National Monument." In T.R. Lyons (editor), Remote Sensing: A Handbook for Archaeologists and Cultural Resource Managers. Washington D.C., 39-60.

Morain, S.A. and T. Bridge, 1978. "Remote Sensing: Instrumentation for Non-Destructive Exploration of Cultural Resources." In T.R. Lyons (editor), Remote Sensing: A Handbook for Archaeologists and Cultural Resource Managers. Washington D.C., 9-17.

Myers, J.W., 1978. "Balloon Survey Field Season," 1977, Journal of Field Archaeology 5:145-159.

- Panayiotopoulos, B. 1985. Plethysmos kai oikismoi tes Peloponnesou. 13os-18os aionas. (in modern Greek) Athens.
- Pollard, E., M.D. Hooper and N.W. Moore, 1974. Hedges, London.
- Rackham, O. 1986. The History of the Countryside, London.
- Sever, T. 1985. Conference on Remote Sensing: Potential for the Future, Mississippi.
- Sever, T.L. 1983. NASA Feasibility Study to Determine the Utility of Advanced Remote Sensing Techology in Archaeological Investigations, Report No. 227, Mississippi.
- Schalk, R.F. and T.R. Lyons, 1976. "Ecological Applications of Landsat Imagery in Archaeology: An Example from the San Juan Basin, New Mexico." In Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archaeological Exploration, Washington D.C.
- Sfikas, G., 1984. Trees and Shrubs of Greece. Athens.
- Sheets, P. and T. Sever, 1988. "High-Tech Wizardry," Archaeology 41, pp. 28-35.
- Shelmerdine, C. W. 1984. "The Perfumed Oil Industry at Pylos" in Pylos Comes Alive, eds., T. G. Palaima and C. W. Shelmerdine, New York, pp. 81-95.
- Shelmerdine, C.W. 1985. "The Perfume Industry of Mycenaean Pylos," (Studies in Mediterranean Archaeology), 34, Göteborg.
- Sutton, S.B. 1988. "'Village in a Nation of Migrants?," Journal of Modern Greek Studies 6, pp. 187-215.
- Szakielada, K.H., 1988. Satellite Monitoring of the Earth New York.
- Topping, P. 1972. "The Post-Classical Documents" in The Minnesota Messenia Expedition: Reconstructing a Bronze Age Regional Environment, eds. W. McDonald and G. Rapp, Minneapolis, pp. 64-80.
- Van Andel, T.H. and C. Runnels, 1987. Beyond the Acropolis: A Rural Greek Past, Stanford.
- Van Andel, T.H. and S. Sutton, 1987. Landscape and People of the Franchthi Region, (Excavations at Franchthi Cave, Greece), 2, Bloomington.
- Vyronis, S. 1981. "The Evolution of Slavic Society and the Slavic Invasions in Greece: First Major Attack on Thessalonika in A.D. 597," Hesperia 50, pp. 378-390.
- Wagstaff, M. 1982. The Development of Rural Settlements, London.
- Weithmann, M.M. 1978. "Die slavische Bevölkerung auf der griechischen Halbinsel," (Beiträge zur Kenntnis Südosteuropas und des Nahen Orients), 31, Munich.
- Wright, J. 1990. "The Nemea Valley Archaeological Project: A Preliminary Report," Hesperia 59, pp. 579-659.

USE OF GROUND-PENETRATING RADAR TECHNIQUES IN
ARCHAEOLOGICAL INVESTIGATIONS

James A. Doolittle* and W. Frank Miller**

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS54-32
201791
p-12

ABSTRACT

Ground-penetrating radar (GPR) techniques are increasingly being used to aid reconnaissance and pre-excavation surveys at many archaeological sites. As a "remote sensing" tool, GPR provides a high resolution graphic profile of the subsurface. Radar profiles are used to detect, identify, and locate buried artifacts. Ground-penetrating radar provides a rapid, cost effective, and nondestructive method for identification and location analyses. The GPR can be used to facilitate excavation strategies, provide greater areal coverage per unit time and cost, minimize the number of unsuccessful exploratory excavations, and reduce unnecessary or unproductive expenditures of time and effort.

INTRODUCTION

Archaeologists are becoming aware of the advantages of using ground-penetrating radar (GPR) for reconnaissance and pre-excavation surveys. Ground-penetrating radar is being used to facilitate excavation strategies, decrease field time and costs, and accurately locate buried artifacts and archaeological features. The GPR compliments traditional methods of archaeological investigation. Compared with traditional methods, GPR techniques are faster, provide greater areal coverage per unit time and cost, and are non-destructive.

Ground-penetrating radar (GPR) techniques have been used to locate buried artifacts in many areas of the world (Batey, 1987; Berg and Bruch, 1982; Bevan, 1977, 1984a and 1984b; Bevan and Kenyon, 1975; Bevan et al., 1984; Dolphin and Yetter, 1985; Doolittle, 1988; Grossman, 1979; Imai et al., 1987; Kenyon, 1977; Mayer, 1989; Parrington, 1979; Sakayama et al., 1988; Vaughan, 1986; Vickers and Dolphin, 1975; Vickers et al., 1976; and Weymouth and Bevan, 1983). These studies document the efficiency of using GPR methods to pinpoint the location of buried artifacts, aid site interpretations, and facilitate excavation planning.

Ground-Penetrating Radar

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. Short pulses of electromagnetic energy in the VHF and UHF frequency range are transmitted into the ground from an antenna which is moved along the ground surface. The pulses form a wavefront which moves downward until it contacts an interface separating layers of differing dielec-

*Soil Specialist, USDA-Soil Conservation Service, 160 East 7th Street, Chester, PA 19013; **Director Mississippi Remote Center, Mississippi State University, Mississippi State, MS 39762

tric properties. There a portion of the pulse's energy is reflected back to the receiving antenna. The receiving unit samples and amplifies the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a graphic recorder or are recorded on magnetic tape for future playback or processing. The graphic recorder uses a variable gray scale to display the reflected waveforms.

The radar unit used in the studies reported in this paper is the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. The SIR System-8 (Figure 1)



Figure 1. Frank Miller operating radar control and recording units during an archaeological investigation in Israel.

consists of the Model 4800 control unit, the ADTEK SR 8004H graphic recorder, the ADTEK DT 6000 digital tape recorder, a power distribution unit, a 30 meter transmission cable and antennas. The system is powered by either a 12-volt vehicular battery or two, deep cycle marine batteries. Detailed techniques for using GPR in the field have been described by Doolittle (1987), Morey (1974, and Olson and Doolittle (1985).

The 120 and 500 MHz antennas were used in the field studies reported in this paper. The lower frequency 120 MHz antenna has greater powers of radiation, longer pulse widths, and emits signals that are less rapidly attenuated by earthen materials than the signals emitted from the higher frequency, 500 MHz antenna. The 500 MHz antenna is smaller, provides better resolution of subsurface features, but is limited to shallow profiling depths and its performance is severely restricted in medium and fine textured soils. These relatively light-weight antennas can be hand-towed along survey lines at an average speed of 2.0 km/h or pulled behind a vehicle at speeds of 7 to 8 km/h or greater.

Survey Procedures

The most accepted and perhaps efficient method to detect and chart the location of buried artifacts with the GPR is to establish a grid across the survey area. Survey procedure involves moving the radar antenna along each grid line at a constant rate. As it is being pulled along grid lines, the antenna remains in contact with the surface to maximize the coupling of the radiated energy into the ground.

Generally, rectangular grids are preferred, though Bevan (1977), in a GPR study of a military earthworks, described a grid consisting of survey lines radiating outwards from a fort like spokes of a wheel. Berg and Bruch (1982) described the use of "wildcat" surveys. These surveys consist of random traverses. Wildcat surveys are an effective method to quickly reconnoiter large areas for archaeological features or to locate areas having concentrations of buried artifacts.

Grid interval is dependent upon several factors and is usually a compromise between the purpose of the survey, available time, features being identified, local ground conditions, desired detection probability, and desired accuracy. Often, in preliminary or pre-excavation reconnaissance surveys a large grid interval is used to define the general location of subsurface anomalies or the gross characteristics of a site. Once the general locations of anomalies have been defined, a smaller grid interval can be used. Closely spaced grid intersects help to pinpoint the location, define the spatial extent, and resolve the identity of subsurface anomalies.

The anticipated size of the buried artifacts being defined or located will influence the grid interval. In relatively detailed surveys, grid intervals of 0.6 to 1.0 meter were used to detect grave sites (Hoving, 1986; Strongman, 1988; and Vaughan, 1986), 1.0 to 3.0 meters to locate buried hearths and foundation walls (Batey, 1987; Bevan et al., 1984; Doolittle, 1988; Fischer et al. 1980; and Grossman, 1979), and 5.0 to 10.0 meters to define the general location of buried dwellings (Imai et al., 1987; Vickers et al., 1976; and Weymouth and Bevan, 1983).

Factors Affecting the Radar's Performance

The performance of the GPR is highly site specific and interpreter dependent. The profiling depth of the GPR is, to a large degree, determined by the electrical properties of soils. Conductive soils rapidly attenuate the radar's energy and restrict its profiling depth. Absorptive attenuation losses of electromagnetic energy (Duke, 1990) increases with: (i) the volumetric water content, (ii) the amount and type of salts in solution, and (iii) the amount and type of clays.

Attenuation of electromagnetic energy increases and the profiling depth of the GPR is restricted as the volumetric water content of soils is increased. Even in arid and semi-arid environments, small amounts of moisture can significantly increase the rate of signal attenuation (Dolphin and Beatty, 1982; Dolphin and Yetter, 1985; Vickers et al., 1976).

Absorptive attenuation losses are directly related to the concentration of dissolved salts in the soil solution. The concentration of ions is dependent upon the clay minerals present, the degree of water-filled porosity, the nature of the ions in solution, and the relative proportion of ions on exchange sites. High rates of signal attenuation and restricted profiling depths caused by relatively

high concentrations of dissolved carbonates within the soil profile were reported in studies conducted by Batey (1987), Doolittle (1988), and Grossman (1979).

Ions absorbed on clay particles undergo exchange reaction with ions in the soil solution and contribute to absorptive attenuation losses in soils. Signal attenuation and restricted profiling depths caused by relatively high clay contents were observed in archaeological investigations conducted by Batey (1987), Dolphin and Yetter (1985), Doolittle (1988; 1989), Vaughan (1986), and Vickers et al. (1976).

Under unfavorable conditions of wet, calcareous, clayey soils, the maximum profiling depth of the GPR is less than 0.5 meters. In addition, as low frequency antennas are required to achieve this profiling depth, resolution of subsurface anomalies is often poor. However, with resistive conditions existing in dry, sandy soils, profiling depths of 5 to 35 meters have been achieved with the lower frequency antennas and 3 to 6 meters with the higher frequency antennas.

Even with favorable site conditions (i.e. dry, sandy soils) the detection of a buried artifact with the GPR can not be assured. The detection of buried artifacts is affected by (i) the electromagnetic gradient existing between an artifact and the soil, (ii) the size, shape, and orientation of the buried artifact, and (iii) the presence of scattering bodies within the soil (Vickers et al., 1976).

The amount of energy reflected back to an antenna by an interface is a function of the dielectric gradient existing between two mediums. The greater or more abrupt the difference in dielectric properties, the greater the amount of energy reflected back to the antenna and the greater the amplitude or intensity of the image recorded on the radar profile. Buried artifacts with dielectric properties similar to the surrounding soil matrix are poor reflectors of electromagnetic energy and are often difficult to discern on radar profiles (Doolittle, 1988; Mayer, 1989; Vaughan, 1986).

The size, orientation, and depth to an artifact affects GPR interpretations. Large objects reflect more energy and are easier to detect than small objects. Small artifacts, unless directly beneath the path of the radar antenna may be missed. In addition, small, deeply buried artifacts are difficult to discern on radar profiles. This is because the reflective power of an object decreases proportional to the fourth power of the distance to the object (Bevan and Kenyon, 1975).

The presence of scattering bodies in the soil complicates radar interpretations and affects the performance of the GPR. Strongly stratified soil horizons, stones and cobbles, tree roots, animal burrows, modern cultural features or disturbed soil conditions produce undesired reflections which often complicate the radar imagery and mask the presence of buried artifacts. The detection of buried artifacts was complicated by scattering bodies in radar surveys conducted by Dolphin and Yetter (1985), Doolittle (1988), and Vaughan (1986).

In spite of these environmental constraints, an experienced radar operator can successfully use GPR techniques at many archaeological sites. The following examples are provided to illustrate the interpretative utility and the efficiency of using ground-penetrating radar techniques for archaeological investigations.

CASE STUDIES

Tell Halif, Israel

In a cooperative study conducted by the USDA-Soil Conservation Service, the Cobb Institute of Archaeology, and Mississippi State University at Tell Halif near Lahav, Israel, GPR techniques were used to define the general location of a large buried structural complex. Tell Halif has been the inhabited for more than 5000 years and is considered, by some biblical scholars, to be the site of ancient city of Ziklag. A cluster of grain silos were unearthed in an excavation area on a terrace adjacent to the tell (Cole, 1988). Archaeologists wondered whether these features represented an isolated structure or were part of a larger complex.

An exploratory GPR traverse was conducted with the 120 MHz antenna in an area between two excavations (Figure 2). Figure 3 is the radar profile from this GPR traverse. The profile revealed the two opposing walls of a silo and helped to establish the extent and dimension of this structure.

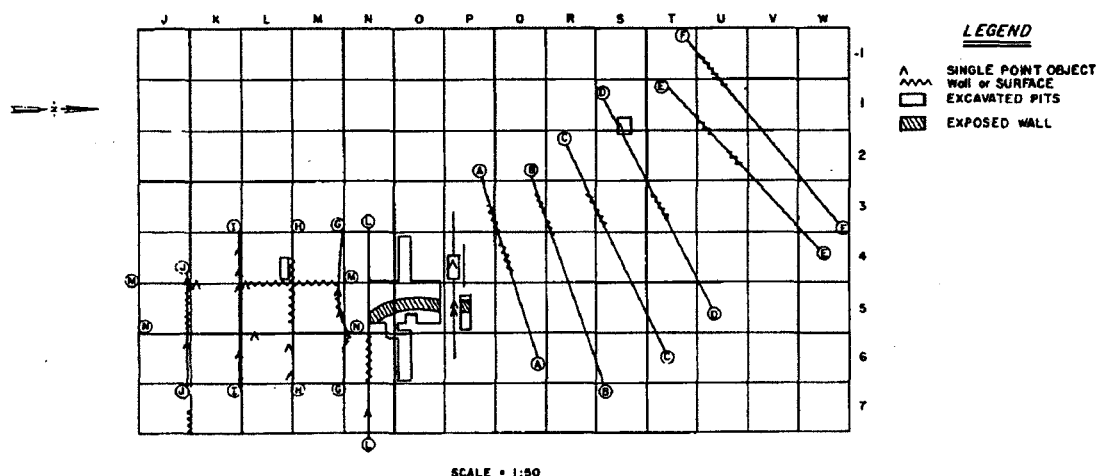


Figure 2. Plot of radar traverses along terrace, Tell Halif, Israel.

In Figure 3, several images have been identified. The horizontal black lines (A) are reflected images from the ground surface. These lines represent the air/soil interface. The dark bands represent the positive and negative signal amplitudes. The intervening white band is the zero or neutral crossing between the positive and negative signal amplitudes. In Figure 3, the next series of dark bands (B) represents a composite reflection from several closely spaced, surface and near surface features. These images represent variations in dielectric properties caused by changes in surface roughness, texture, horizons, compaction, organic matter content, coarse fragments, and/or moisture content within the upper 40 to 50 cm of the soil profile.

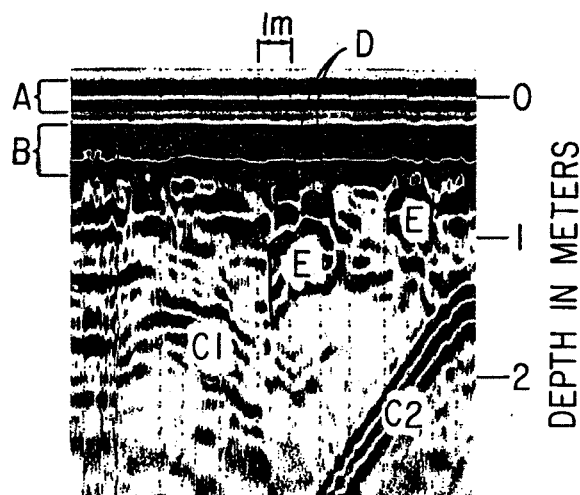


Figure 3. Radar profile from exploratory traverse with the 120 Mhz antenna along terrace, Tell Halif, Israel.

Subsurface interfaces are expressed below the surface images. In Figure 3, the outer clay (E) and stone (D) walls of the grain silo have been identified. Also identified in Figure 3 are false echoes from overhanging tree limbs (C1) and utility lines (C2).

In Figure 3, the effective profiling depth is only 1.2 meters. At Tell Halif, moderately-fine textured (27 to 35 percent clay), calcareous soils limited the profiling of the 120 MHz antenna to depths of 1.0 to 1.5 meters. Below these depths the radar energy was so attenuated that reflected images from subsurface anomalies were too indistinct to be discerned.

After some of the interpretations from the exploratory radar traverse were confirmed in an excavated pit, two GPR survey areas were established across the terrace. One survey (Figure 2, lines A through F) was established with survey lines spaced at irregular intervals, parallel with the slope. Reference points were marked at 2.5 meter intervals along each survey line. Survey lines varied in length from 20 to 26 meters. The second survey area consisted of an irregular grid with a 5 meter interval. Survey lines (Figure 2, lines G through N) varied in length from 10 to 26 meters.

After the completion of the radar survey, the radar profiles were examined and annotated in the field. Exploratory pits were opened along traverses D and H. These excavations confirmed the presence of subsurface anomalies and revealed a clay wall underlain by a layer of stones and pebbles, and double row, mud brick interior walls along traverses H and D, respectively. Symbols (see Figure 2) were used to plot the location of subsurface anomalies and walls. In Figure 2, only the most readily discernible subsurface anomalies were plotted. Poorly resolved or questionable subsurface anomalies were not depicted on this plot.

The GPR survey at Tell Halif reveal a cluster of subsurface anomalies along the rim of the terrace. Interpretations of the radar profiles support contentions that the grain silos were part of a larger structural complex. At this site, the GPR survey facilitated site interpretations and assisted excavation strategies. However, additional excavations and more closely spaced radar traverses would be needed to confirm the identity and extent of this buried structural complex.

Rockwell Mound, Havana, Illinois

In a cooperative study conducted by the USDA-Soil Conservation Service, Havana Park District, and Dickson Mound Museum, GPR techniques were used in Havana, Illinois to determine the origin of a mound in the center of the city.

Rockwell Mound covers nearly two acres, about all of Rockwell Park, in Havana, Illinois. The park had been the site of speeches by Abraham Lincoln and Stephen Douglas during their 1858 campaigns for the United States Senate. In 1987, the mound was placed on the National Register of Historic Places after pieces of Indian pottery were unearthed in a small exploratory pit. However, skepticism about the origin of the mound remained. Many believed the site to be an Indian burial or ceremonial mound, others believed the mound to be one of many natural sand dunes which are ubiquitous along this portion of the Illinois River.

In June 1990, a grid with a ten meter interval was established across the two acre park for the purpose of confirming the mounds origin. This grid interval was considered adequate for defining the general subsurface characteristics of the site and the location of any large buried structures.

Results from previous GPR studies of Indian mounds and middens in Oklahoma (Weymouth and Bevan, 1983), Wisconsin (Bruzewicz et al., 1986), and Louisiana (Mayer, 1989) were varied as profiling depths and resolution were limited by conductive soils. However, the soils at Rockwell Mound are predominantly coarse textured and electrically resistive. These favorable soil features afforded adequate profiling depths (about 4 meters) and high resolution of subsurface features.

In Figure 5, radar profiles from Rockwell Mound (A) and a nearby natural sand dune (B) are displayed. The radar profiles have been terrain corrected using the RADAN software program. Relief varied from 4.9 meters at Rockwell Mound to 7.9 meters on the sand dune. Using the 120 MHz antenna, a profiling depth of about 4 meters was attained.

Two distinct interfaces (a and b) have been identified on the radar profile of Rockwell Mound (Figure 5A). A cluster of subsurface anomalies (c) which occur near the summit of Rockwell Mound have been identified in Figure 5A.

Interface "a" is continuous beneath the summit of Rockwell Mound and is believed to separate to distinct layers of basket-loaded fill materials. Near the location of an exploratory pit (Esarey, 1987) depth to this interface conformed with the measured depth of a buried cultural layer. The image of interface "a" is inconsistent with the natural stratigraphy observed with the radar in dunes. Generally sand dunes, formed from the accretions of migrating sands, have patterns of slip faces and are cross stratified with observable foresets and topsets. These features were not apparent on the radar profiles from Rockwell Mound.

The radar profile from a nearby natural sand dune (Figure 5B) is distinctly different from the radar profiles obtained at Rockwell Mound. Several weakly expressed images are evident in the radar profile of the natural sand dune. These images include an unidentified soil interface along the dunes leeward margin (a), sub-parallel foreset layers (b), several point reflectors (c), and a weakly expressed erosion surface or soil horizon which parallels the soil surface along the dune crest (d).

Major interfaces within Rockwell Mound were more contrasting and continuous than the interfaces within the natural sand dune. Within Rockwell Mound, these interfaces appear to be arranged in a sequence of tiers. In addition, the imagery from Rockwell Mound lacks the foreset layers evident in the sand dune. Based on the interpretation of the radar profiles, archaeologists were satisfied that Rockwell Mound is an Indian mound.

Kualoa Regional Park, Waikane, Hawaii

In a cooperative study conducted by the USDA-Soil Conservation Service and the State of Ha-

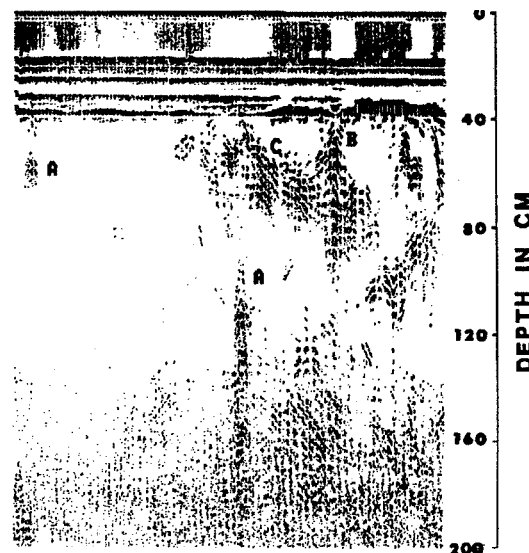


Figure 4. Radar profile of traverse made with 120 MHz antenna at Kualoa Regional Park, Oahu, Hawaii.

waii, Department of Land and Natural Resources, Historic Preservation Program, the potential of using GPR techniques for archaeological investigations in the Hawaiian Islands was explored. This study addressed the growing need for the development of a rapid, economical, and non-destructive method for archaeologists to assess sites along the coastal areas of the Hawaiian Islands. Many of these coastal areas are underlain by predominantly coarse-textured, calcareous soils formed from coral.

At the Kualoa Regional Park near Waikana on the Island of Oahu, GPR techniques were used to chart the location of subsurface anomalies within an archaeological site. In March 1990, several random transects were conducted with the 500 MHz antenna across this site.

Figure 4 is a representative profile from the study site. Subsurface anomalies identified included (i) a known buried metallic reflector at 40 cm (B), (ii) several subsurface anomalies believed to be burials (A), and (iii) a buried cultural horizon (C). The buried metallic reflector was exhumed. The buried cultural horizon was traced laterally into a beach scarp where it was exposed and identified.

In Figure 4, the randomly spaced subsurface anomalies (A) believed to be burials occur at depths ranging from about 60 to 90 cm. Commonly, in prehistoric burials, bodies were interred in a "flexed" or fetal position. Though this procedure reduces the lateral extent and the probability of locating a burial with a single pass of the antenna, it increases the likelihood of detection if the antenna passed directly over a burial site. If passed directly over by an antenna, the concentration of artifacts and bones in these burials increases the probability of detection.

Similar results were achieved with the 500 MHz antenna in areas of coarse-textured, calcareous soils which fringe the islands of Hawaii, Maui, Oahu, and Kauai. As many of these areas are being developed for resorts and homesites, the speed and efficiency of using GPR techniques to nondestructively detect ancient burials is significant. With the GPR, the presence and extent of ancient burials can be quickly assessed and sites protected without disturbance.

CONCLUSIONS

The use of ground-penetrating radar for archaeological investigations is in an active stage of growth and development. This trend has been accelerated by growing commercialization and familiarity with the GPR's applicability to archaeological investigations. However, the use of GPR techniques has been limited because of (i) limited knowledge of its performance in various media and geographic locations, (ii) rapid rates of signal attenuation and restricted profiling depth in certain media, and (iii) results which are often dependent upon the skill and experience of the operator. Ground-penetrating radar techniques compliment but do not replace traditional archaeological methods. Results from GPR investigations are often tentative and incomplete until interpretations are confirmed by traditional archaeological methods. However, GPR techniques can be used to facilitate excavation strategies, to provide greater areal coverage per unit time and cost, to minimize the number of unsuccessful exploratory excavations, and to reduce unnecessary or unproductive expenditures of time and effort.

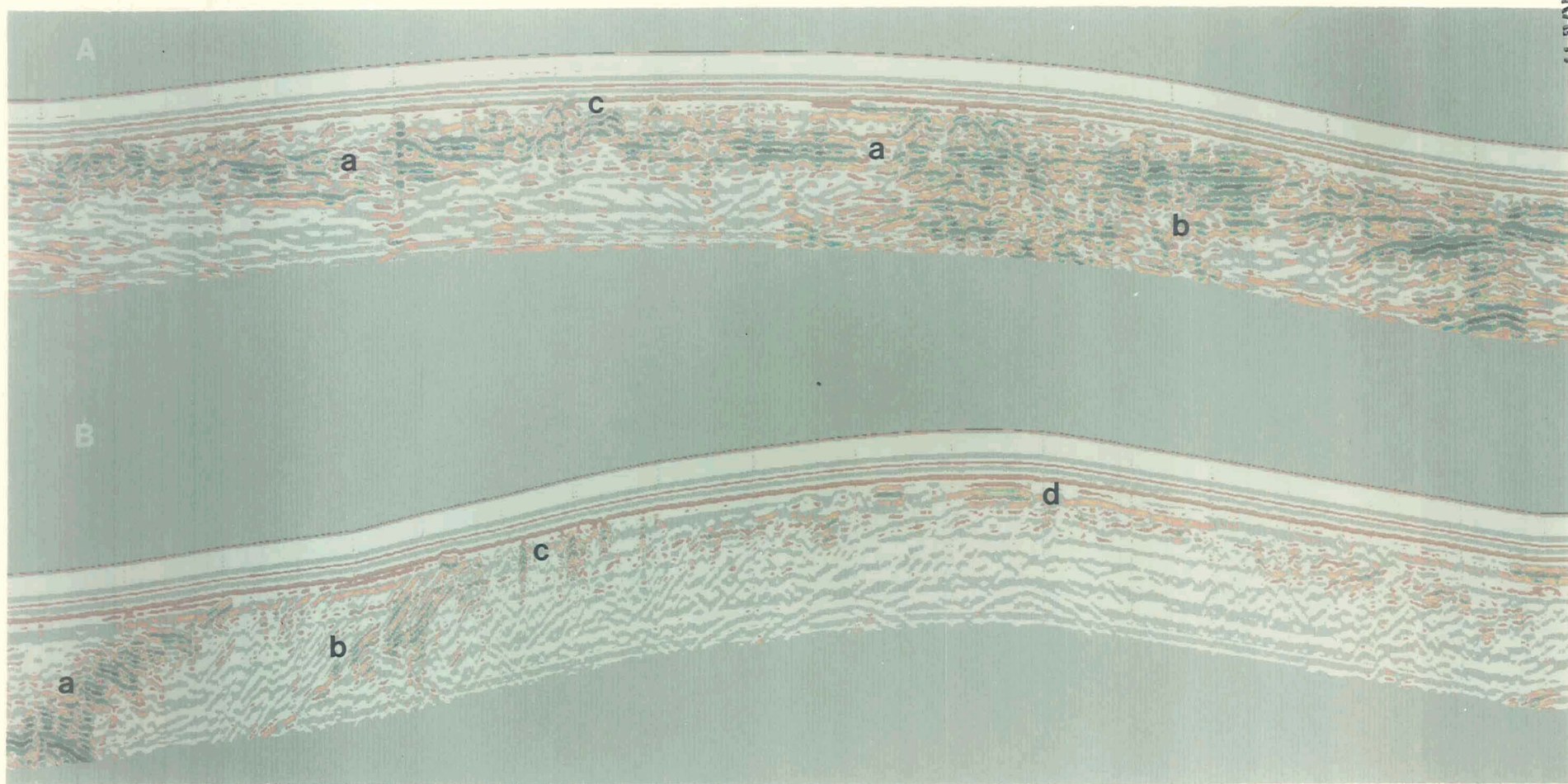


Figure 5. Radar profiles of traverses made with the 120 MHz antenna along Rockwell Mound (A) and a natural sand dune (B).

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Joe Seger, Director of the Cobb Institute of Archaeology, Mississippi State University; Duane Esarey, Staff Archaeologist, Dickson Mound Museum; and Don Hibbard and Nancy McMahon, Director and Staff Archaeologist of the Hawaiian Department of Land and Natural Resources, Historic Preservation Program for their technical support and field assistance.

REFERENCES

- Batey, Richard A., 1987. Subsurface interface radar at Sepphoris, Israel, 1985. *Journal of Field Archaeology* 14(1):1-8.
- Berg, F. and H. Bruch., 1982. Georadar: Archaeological interpretation of soil radar data. Second Nordic Conference on the Application of Scientific Methods in Archaeology. Elsinore, Denmark, 17-19 August 1981. *PACT* 7:285-294.
- Bevan, Bruce W., 1977. Ground-penetrating radar at Valley Forge. Geophysical Survey Systems, Inc. Hudson, New Hampshire.
- Bevan, Bruce W., 1984a. Environmental effects on ground-penetrating radar. In: Abstract, 54th Annual International SEG Meeting, held at Atlanta, GA., Dec. 2-6, 1984, pp. 201-204.
- Bevan, Bruce W., 1984b. Looking backward: geophysical location of historic structures. In: *The Scope of Historical Archaeology, Essays in honor of John L. Cotter*. David G. Orr and Daniel G. Crozier (eds.). Temple University, Philadelphia., pp. 285-301.
- Bevan, Bruce and Jeffrey Kenyon. 1975. Ground-probing radar for historical archaeology. *MASCA* (Museum Applied Science Center for Archaeology, University of Pennsylvania, Philadelphia) Newsletter 11(2):2-7.
- Bevan, Bruce W., David G. Orr, and Brooke S. Blades., 1984. The discovery of the Taylor House at the Petersburg National Battlefield. *Historical Archaeology* 18:64-74.
- Bruzewicz, A. J., C. R. Smith, D. E. Berwick, and J. E. Underwood., 1986. The use of ground-penetrating radar in cultural resource management. *Technical Papers 1986 ACSM-ASPRS Annual Convention Vol. 5: 233-242.*
- Cole, D. P., 1988. Hi-tech archaeology: ground-penetrating radar. *Biblical Archaeology Review* 14(1): 38-40.
- Dolphin, L. and W. Beatty., 1982. The potential of ground-penetrating radar in Jerusalem. *SRI International*, Menlo Park, CA., pp.4.
- Dolphin, L. and T. J. Yetter., 1985. Geophysical survey at Third Mission Site, Santa Clara University. *SRI Project 8745. SRI International*, Menlo Park, CA., p.56.

- Doolittle, J. A., 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. In *Soil Survey Techniques*, Soil Sci. Soc. Am. Special Pub. No 20, pp. 11-32.
- Doolittle, J. A., 1988. Ground Penetrating Radar (GPR) survey at Tell Halif, Israel. In *Technical Proceedings of the Second International Symposium on Geotechnical Applications of Ground-Penetrating Radar*, Gainesville, Florida, March 6-10, 1988, pp. 180-213.
- Doolittle, J. A., 1989. Ground Penetrating Radar (GPR) survey of the Poverty Point site, Northern Louisiana. In: Jon L. Gibson (editor), *Digging on the Dock of the Bay(ou): The 1988 Excavations at Poverty Point*. University of Southwestern Louisiana, Center for Archaeological Studies, Report No. 8, pp. 207-209.
- Duke, Steven., 1990. Calibration of ground penetrating radar and calculation of attenuation and dielectric permittivity versus depth. M.S. thesis. Colorado School of Mines, Golden. T-3920. pp. 236.
- Esarey, Duane., 1987. Havana's hidden mound. *Illinois Antiquity* 19 (1): 6-10.
- Fischer, Peter M., Sven G. W. Follin and Peter Ulriksen. 1980. Subsurface interface radar survey at Hala Sultan Tekke, Cyprus. *Swedish Annual Studies in Mediterranean Archaeology* 63:48-64.
- Grossman, Joel W., 1979. Ground-penetrating radar survey at Raritan Landing: an underground map of a buried settlement. *Annual Meetings of the Society for American Archaeology*, Vancouver, British Columbia, April 23-26, 1979, pp.15.
- Hoving, G. L., 1986. Buried body search technology. *Identification News*, Feb., pp. 3-15.
- Imai, T., T. Sakayama, and T. Kanemori. 1987. Use of ground-probing radar and resistivity surveys for archaeological investigations. *Geophysics* 52(2): 137-150.
- Kenyon, Jeff L., 1977. Ground-penetrating radar and its historical application to a historical archaeological site. *Historical Archaeology* 2:48-55.
- Mayer, F. J., 1989. Ground Penetrating Radar (GPR) Subsurface Testing, Poverty Point. In: Jon L. Gibson (editor), *Digging on the Dock of the Bay(ou): The 1988 Excavations at Poverty Point*. University of Southwestern Louisiana, Center for Archaeological Studies, Report No. 8, pp. 211-227.
- Morey, R. M., 1974. Continuous subsurface profiling by impulse radar. In: *Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction*, held at Henniker, N., Aug. 11-16, 1974, pp. 212-232.
- Olson, C. G. and J. A. Doolittle. 1985. Geophysical techniques for reconnaissance investigations of soils and surficial deposits in mountainous terrain. *Soil Sci. Soc. Am. J.* 49(6): 1490-1498.

Parrington, Michael., 1979. Geophysical and aerial prospecting techniques at Valley Forge National Historical Park, Pennsylvania. *Journal of Field Archaeology* 6(2):193-201.

Sakayama, T., T. M. Osada, and K. Tamura., 1988. Some examples of archaeological investigations using ground probing radar. In: *Technical Proceedings of the Second International Symposium on Geotechnical Applications of Ground-Penetrating Radar*, Gainesville, Florida, March 6-10 1988, pp. 57-60

Strongman, K. B., 1988. Forensic application of ground-penetrating radar. In: *Geologic Survey of Canada Workshop on Ground Penetrating Radar*, Ottawa, Canada, May 24-26, 1988.

Vaughan, C. J., 1986. Ground-penetrating radar survey in archaeological investigations. *Geophysics* 51(3):595-604.

Vickers, Roger S. and Lambert T. Dolphin., 1975. A communication on the archaeological radar experiment at Chaco Canyon, New Mexico. *MASCA Newsletter* 11(1):1-3.

Vickers, Roger, Lambert Dolphin, and David Johnson., 1976. Archaeological investigations at Chaco Canyon using subsurface radar. In: *Remote Sensing Experiments in Cultural Resource Studies*, assembled by Thomas R. Lyons, Chaco Center, USDI-NPS and University of New Mexico, pp. 81-101.

Weymouth, John W. and Bruce W. Bevan., 1983. Combined magnetic and ground penetrating radar survey of an archaeological site in Oklahoma. In: *Digest International Geoscience and Remote Sensing Symposium (IGARDD'83')* vol. 1, pp. 1.1-1.4.

GIS MODELING OF ARCHAEOLOGICAL SITE LOCATIONS: A LOW-TECH APPROACH

Eugene M. Futato*

55-43

201792
p. 16

ABSTRACT

This paper presents a GIS-type analysis of archaeological site locations using a dBase III plus program and a desk top computer. A previously developed model of site locations in the Sequatchie Valley of northeastern Alabama is tested against known site locations in another large survey area there. The model fails to account for site locations in the test area. A model is developed for the test area and indicates the site locations here are indeed different. Whether this is due to differences in site locations on a sub-regional level, or to sample error in the original model is unknown.

INTRODUCTION

There are a variety of systems available today for various sorts of GIS analyses, and their capabilities are truly amazing. But we should remember that GIS analysis is more than just hardware and software. It is also a way of thinking; a body of theories, methods, and techniques to be applied to the problem at hand. The application of these is not reliant upon elaborate technology. This paper describes a GIS based analysis of archaeological site distributions which uses a dBase III Plus program, called SITEMODL, written by this author. It may seem a contradiction in terms to refer to a dBase program as low-tech, but by comparison, it clearly is so.

BACKGROUND

The method of modeling archaeological site distribution presented in this paper was first developed and used in a survey for the Tennessee Valley Authority of above pool lands in the Guntersville Lake area of Alabama and Tennessee (Solis and Futato 1987). Several specific criteria guided the development of techniques for the modeling. Primary among these was the nature of the survey project itself. The survey tracts were defined by TVA's land use plan and were discontinuous and irregular in size, shape, and distribution. Also, the intensity of survey coverage was based on land use. Tracts scheduled for agriculture, development, or other surface disturbances were completely surveyed. Tracts for forestry, wildlife, or other less disruptive use were subjected to partial or preliminary survey, emphasizing areas where site location was considered likely. Therefore, the design for the models had to accommodate the field techniques, rather than the reverse.

The models were developed to serve as tools in planning and land management. This did not mean that archaeological significance was secondary, however, because without archaeological meaning, the models would have no meaning in planning. But it did mean that the models

*Senior Archaeologist/Curator of Archaeological Collections University of Alabama, State Museum of Natural History, Division of Archaeology

were designed to be understood and utilized by persons other than archaeologists. Also, the models were designed to be easily applied to unsurveyed areas, and to use readily available sources of information, USGS 7.5' topographic maps and county soil survey reports.

The other elements which guided the development of this modeling method were the beliefs and biases of this author. Primary among these is the opinion that site distribution models are incomplete if they do not take into account both site and non-site locations. Models which consider only site locations, or which are based only on the analysis of site locations are weakened by lack of consideration of non-site locations. For example, statements about site distribution often take the form of, "Seventy five percent of all Mississippian sites are located on sandy loam soils." But how is this statement to be interpreted? A correlation is implied, and a strong positive correlation might be inferred. But is the correlation strong? Is the correlation really positive? Does a correlation even exist? We simply cannot judge from the evidence given. If sandy loam soils make up twenty five percent of the environment, the correlation is positive, and relatively strong. If sandy loam soils make up ninety five percent of the environment, the correlation is negative. If sandy loam soils make up seventy five percent of the environment the correlation is random. Statements about observed site associations with environmental settings have meaning only if they can be measured against expected site associations.

The final principle guiding the modeling methods was a belief that the statistical aspects should be kept simple. One reason is that simple methods would make the models easier to understand and utilize. It is also believed that simple methods are more appropriate to the data at hand. The degree of inherent error in the data and map sources used is such that sophisticated techniques would be unnecessary or even inappropriate. The square root of 4.0000 is 2.0000 but the square root of 4 ± 0.5 is an unknown quantity anywhere between 1.8708 and 2.1213. This uncertainty is multiplied at each step in calculation. If the square root of 4 ± 0.5 is multiplied by 2 and then squared, the answer is between 13.9996 and 17.9996. We must learn to understand, accept, and work within the limitations of our data. It is simply not possible to take measurements to the nearest meter and perform meaningful calculations to the nearest millimeter.

After consideration of all the above factors, the following outline of procedures was adopted for the model development. The specific procedures are described in the next section of this paper.

1. The analysis would consider units of land surface, not just site locations.
2. Environmental variables generally accepted as relating to site occurrence would be recorded for each unit.
3. The distribution of environmental variable states in units with sites would be compared to the distribution in all units.
4. The results of this analysis would be used to score the variable states in regard to site association.
5. The scores for the variable states would then be used to score the units.
6. The scores of units with sites would then be compared to the scores of units without sites to examine the relationship of unit score and probability of site occurrence.

MODELING TECHNIQUES

Analytical Units and Sampling

After some consideration, the unit of analysis for the site distribution models was defined as a 1 ha tract bounded by 100 m intervals on the Universal Transverse Mercator grid system. The UTM grid was used in preference to the General Land Office survey system, i.e. township, range, and section, because the latter grid is not uniform and it is not possible to define and maintain a consistent unit definition. Sections are not all the same size and shape. Using the UTM grid to define the study units accommodates the use of irregular and discontinuous survey tracts. Survey tracts in effect become cluster samples of 1 ha units.

The 1 ha unit size was chosen on practical grounds. The unit is an even division of the 1000 m grid and units are easily defined within the system. Experimentation with 50 m units showed these units to be too small to work with easily given the working map scales and very numerous and redundant. Experimentation with 200 m units showed these to be so large as to produce very few units and with data much too generalized, particularly in regard to soils. The 1 ha unit, therefore, was decided upon by experimentation and what this author calls the Goldilocks principle. "This unit is too large. This unit is too small. But this unit is just right."

The sample universe for model development is then defined as those 1 ha sample units in the study area which lie entirely within survey tracts which have been subjected to archaeological survey of such thoroughness that one can be reasonably assured that all archaeological sites, with the exception of deeply buried sites, have been recorded. In practical terms, survey areas of less than about 100 acres are of little use, and the larger the area the better. Depending on how the UTM grid falls with respect to section lines, for instance, a 40 acre quarter of a quarter section will yield usually two and sometimes four sample hectares.

Two sample populations are then drawn from the sample universe. The first population is a regular 25 per cent sample. The 25 per cent sample hectares are defined as those whose northing and easting are evenly divisible by 200. The second population is the site sample, all hectares containing all or part of an archaeological site. The samples are drawn independently and hectares may occur in both, if appropriate. It is not necessary to record the data twice when this occurs.

Environmental Variables

Five environmental variables generally accepted as relating to site location are recorded for each sample hectare. These are: soil type, nearest water source, distance to the nearest water source, elevation, and relief. Soil type is recorded by reference to the most recent county soil report. If the hectare contains more than one soil type, the dominant type is recorded. The great age span of available reports, over 75 years in Alabama, and the resulting differences in the classification and mapping of soil units over this time are a significant source of inconsistency in the data.

The nearest water source and distance to that source are taken from USGS 7.5' maps. Stream order is determined in the following manner. Intermittent streams depicted on the maps and the

smallest permanent streams are considered first order. The confluence of two first order streams creates a second order stream, two second order streams flow together to make a third order stream, etc. Tributary streams larger than fourth order are coded as major tributary streams. Lakes and springs are recorded as the water source only if they are natural and are shown on the topo map. Distance to water is measured from the center of the hectare and recorded in 100 m intervals.

Elevation is recorded as the 20 ft contour interval within the hectare passing nearest to the center of the hectare. If no 20 ft interval passes through the hectare, the next higher interval is used. The overall accuracy of this variable, therefore, is ± 20 ft. The next interval was used instead of the nearest interval because many survey projects are related to some form of water development and the contours below the site are inundated and not depicted. Thus the nearest interval is often indeterminate. Topo maps for areas of less little relief may have 10 ft intervals. These are not recorded in order to keep the data set consistent.

Relief is the difference between the highest and lowest 20 ft contour interval in the hectare. Again 20 ft intervals only are used in order to provide consistent data. Relief is a minimum figure, subject to a -20 ft error if no contour line passes through the hectare, and a 40 ft error if one or more lines pass through the hectare.

All data on the sample hectares are entered into a dBase III Plus file. The data file includes the UTM coordinates of the hectare, the sample population, and the five environmental variables states just discussed, along with a number of other data fields. These additional fields include various geographic information such as state, county, topographic map, drainage basin, topographic setting, and physiographic district, plus all identified archaeological components, by stage, at any site which is included in the hectare. This information permits the file to be sorted by any number of criteria in order to produce a model tailored to a wide range of specific circumstances. Also listed for each hectare is a reference number for the report from which the survey data was taken, and the site numbers for any sites in the hectare.

THE MODELS

All models are by nature both descriptive and predictive. The site distribution models produced by this program, however, are readily separable into one aspect which is more descriptive in intent and one which is more predictive. The descriptive aspect analyses data from the known sample and yields an account of known site distribution. The predictive aspect operationalizes this known distribution in a format readily applied to other areas. We will consider these aspects separately.

Each variable is treated as though it were an independent variable, even though we recognize that they are not completely independent, certain soil types are found within certain elevation ranges, etc. The method of analysis is relatively simple. The model begins with the calculation of the expected, observed, and relative site frequencies for each environmental variable state in the sample. Table 1 is an example of the results of this portion of the computation, taken from the Guntersville basin analysis referred to again later.

First, the total number of site hectares and the number of site hectares for each attribute state is counted. This is shown in the column for Site Hectares in Table 1. Then the total number of 25

Table 1. Relative Frequencies of Variable States in the Bottom Lands, Guntersville Basin Area.

VARIABLE STATE	SITE HECTARES	TOTAL HECTARES	OBSERVED FREQUENCY	RELATIVE FREQUENCY
Total Stratum	31	228	13.6	1.0
SOIL TYPE:				
Bruno Fine Sandy Loam	3	8	37.5	2.8
Egam Silt Loam	0	8	0.0	0.0
Egam Silty Clay Loam	1	36	2.8	0.2
Egam-Newark Silty Clay Loams	12	36	33.3	2.4
Huntington Fine Sandy Loam	4	8	50.0	3.7
Huntington Silt Loam	9	24	37.5	2.8
Lindside Silt Loam	1	8	12.5	0.9
Lindside Silty Clay Loam	0	4	0.0	0.0
Melvin Fine Sandy Loam	0	12	0.0	0.0
Melvin Silt Loam	0	24	0.0	0.0
Melvin Silt Loam and Silty Clay Loam	0	48	0.0	0.0
Newark Loam	1	0	99.9	99.9
WATER SOURCE:				
First Order	12	104	11.5	0.8
Second Order	0	56	0.0	0.0
Third Order	0	4	0.0	0.0
Major Tributary	0	28	0.0	0.0
River	19	36	52.3	3.9
DISTANCE TO WATER:				
1-100 m	26	144	18.1	1.3
101-200 m	3	52	5.8	0.4
201-300 m	1	12	8.3	0.6
301-400 m	0	12	0.0	0.0
401-500 m	1	0	99.9	99.9
501-600 m	0	8	0.0	0.0
ELEVATION:				
560 ft	0	8	0.0	0.0
580 ft	14	88	15.9	1.2
600 ft	17	124	13.7	1.0
620 ft	0	8	0.0	0.0
RELIEF:				
0	27	204	13.2	1.0
20 ft	4	16	25.0	1.8
40 ft	0	0	NA	NA
60 ft	0	4	0.0	0.0
80 ft	0	4	0.0	0.0

NA = Not Applicable

percent sample hectares and the number for each attribute state is counted and multiplied by four to provide an estimate of the total for the sample universe, shown in the column Total Hectares. The degree to which this sample approximates the entire area to which the model is being applied is a primary determinant of the accuracy of the model.

The next step is the calculation of the expected frequency of site occurrence for each variable state. This is nothing more than the percentage of all hectares which contain sites. In Table 1 there are an estimated 228 total hectares in the sample, and 31 of these, or 13.6 percent, have sites. The expected site frequency for each variable state in this model is, therefore, 13.6. The expected site frequency for each variable state is shown on the first line of each table as the observed site frequency for the total area.

The program then calculates the observed site frequency for the individual variable states by dividing the observed number of site hectares for each state by the estimated total number of hectares for that state. The observed site frequency is, therefore, the percentage of hectares of a variable state which have sites. Finally, the relative site frequency for each state is computed by dividing the observed frequency by the expected frequency. For example, in Table 1 we see that Huntington silt loam was the soil type for an estimated 24 hectares in the surveyed areas, and 9 of these hectares had sites. Thus 37.5 percent of the Huntington silt loam hectares had sites and this is 2.8 times the random expectation of 13.6 per cent. It is possible, especially when the sample size is small or a particular variable state occurs infrequently in the environment, for a site hectare to occur for a variable state which is not represented in the 25 per cent sample. This results in dividing by zero, yielding an infinite observed and relative frequency. When this happens, the program assigns an arbitrary value of 99.9 for these frequencies.

Table 1 also provides an illustration of why site distribution models based on site locations alone may be misleading. If we look at the data for nearest water source, we see that roughly 40 per cent of the site hectares, 12 of 31, occur along first order streams. One might infer from this that there was a strong association of sites with this attribute state, but in a relative analysis, we see that the association is actually slightly below random, because such a large portion of the study area fell into this category.

Predicting Site Occurrences

Consideration of the information in Table 1 will show that these descriptive models may by themselves be used to make general predictions about the occurrence of sites in unsurveyed areas. Referring back to soil types, it can be seen that the survey of an estimated 96 ha of various Melvin series soils encountered no sites. If an unsurveyed tract has this soil type, the occurrence of a site may be considered to be unlikely. On the other hand, any tract falling into one of the Huntington series soils has a relatively high probability of containing a site. Or if we look at the data for distance to water, we see that in the bottom lands the probability of a site occurring in a hectare more than 100 m from water is low.

There is one necessary consideration in the use of any of these models, however. This is the sample size of the variable state being considered. In a relatively small or highly diverse study area, a great many attribute states, particularly soil types, are represented by a very few sample hectares.

The addition of only one or two additional hectares to either the site hectare count or the 25 per cent sample hectare count, or both, could greatly alter the observed and relative site frequencies.

Although the general site distribution probabilities suggested by the descriptive model tables may be adequate for a number of purposes, a more precise method of estimating site probability is also available. An example of a site probability table is presented in Table 2. The first step in the genera-

Table 2. Hectare Scores and Site Frequency in the Bottom Lands, Guntersville Basin Area.

HECTARE SCORE	ESTIMATED NONSITE HECTARES	SITE HECTARES	CUMULATIVE PERCENTAGE SITE HECTARES	SMOOTHED* PERCENTAGE SITE HECTARES
0.3	4	-	0	0
0.4	20	-	0	0
0.5	16	-	0	0
0.6	4	-	0	0
0.7	40	-	0	0
0.8	20	-	0	1
0.9	28	1	3	2
1.0	8	-	(5)	4
1.1	8	1	6	6
1.2	16	1	10	17
1.3	12	5	26	18
1.4	-	-	(28)	23
1.5	8	1	29	20
1.6	4	2	35	14
1.7	-	-	(45)	0
1.8	8	-	(55)	0
1.9	-	-	(64)	50
2.0	4	12	74	76
2.1	-	1	77	82
2.2	-	5	94	100
20.7	-	1	97	100
21.2	-	1	100	100
TOTAL	200	31	-	-

* Percent of all hectares having sites, scores ± 0.1 .

() = Interpolated value.

tion of this table is calculation of the hectare score for each hectare in the model sample. The hectare score for each hectare is simply the mean of the five respective relative frequency scores for the five variable states. The scores of those hectares with sites are then compared to the scores of hectares without sites.

Table 2 is an example of the model output after this process. All hectare scores occurring in the sample are listed in ascending order. The number of site hectares and the estimated total number of hectares are then listed for each score. The estimated total number is, as before, the number of 25 percent sample hectares, multiplied by four. These figures are used to determine the cumulative percentage of all sites included at each score and the percentage of all hectares with that score which contain sites. These two figures are presented in the remaining two columns of the table.

For example, in Table 2, a hectare score of 1.0 or less occurred for an estimated 140 hectares without sites and only 2 hectares with sites. Only 6 per cent of all site hectares have scores of 1.0 or less. Overall, then, the probability of a site occurring in a hectare with a score of below 1.1 must be considered low. On the other hand, scores of 2.0 or greater occurred for only 4 hectares without sites and 18 hectares with sites; and included 58 percent of all hectares with sites.

There is an estimated total of 231 hectares represented in Table 2. This differs a bit from the 228 estimated total hectares in Table 1 because the figures are derived in different ways. The total in Table 1 is the number of 25 percent sample hectares (57) times 4, an estimate of the total sample universe for environmental attributes. The total in Table 2 is the number of 25 percent sample hectares without sites (50) times 4, an estimate of the number of hectares without sites, plus the actual number of hectares with sites (31).

Site probability predictions for unsurveyed hectares are made in the following manner. First, the soil type, water source and distance, elevation, and relief of the hectare must be determined. All required data may be obtained from county soil reports and USGS 7.5' topographic maps, but the information can be obtained from other sources as well. It might be pointed out here that the prediction need not be made only for hectares defined within the 100 m UTM grid, as were the hectares in the model development. For purposes of prediction a hectare is a hectare.

Once the five variable states are recorded, the relative site frequency for each is located on the appropriate table of environmental variable site frequencies. Then the mean of the five scores is computed to determine the hectare score. This score is located on the table of hectare scores and site frequencies, and the probability of site occurrence is read from the table.

Caution must be exercised in the use of any site distribution model, however, to ensure that the model remains a predictive tool and does not become a self-fulfilling prophesy. It would be inappropriate to use this or any other model to decide that few or no sites occur in a particular area, and then declare that area to be site free. In the first place, no model can assure that degree of accuracy. Site locations are simply not that regular and thus predictable. The site distributions in this report contain outliers on either end. Survey archaeologists frequently encounter this in the field. Locations which seem perfect do not always contain sites, and some sites are found in marginal or poor locations. In the second place, even if the model predicts that the probability of site occurrence is only one in a hundred, which is the one? Less than one ridge spur in perhaps a couple of thousand in northwest Alabama contains a Middle Woodland burial mound, but how do you identify the one?

Certainly models can be refined and better modeling techniques will be developed, but models are no substitute for survey. The proper role for these models is in the planning process. As early as possible in planning, the probability of archaeological site location should enter into questions such as the determination of probable project impacts, or in the evaluation of alternative project locations.

Final statements of impact, however, must be based on ground truth.

Model Testing and Refinement

Site distribution models developed by this method are quite amenable to testing. All that is required is to take any future or existing intensively surveyed areas not used in the model development, divide the area into hectares, make predictions, and see if they are correct. Another possible test would be to take the locations of known sites, again excluding those used in model development, apply the model to these locations, and see if sites are predicted. Such predictions could be on either a yes/no or probabilistic nature.

Evaluation of the test results, though, must take the probabilistic nature of the predictions into account. For example, let us assume that we make predictions for four hectares, and each has a 25 per cent site probability. On a yes/no basis, the prediction for each hectare would be less than 50 per cent or a prediction of no site. But on the cumulative probability of four hectares with a 25 percent probability each, we would predict a site in one of the four hectares, and that hectare would be scored as a yes/no error.

This modeling technique has been subjected to only one test in the field. In the second season of the Guntersville Lake area survey, 50 one hectare tracts were intensively surveyed. Yes/no predictions were correct for 42 of these, an 84 per cent accuracy rate. Of the 50 hectares, 29 were assigned a site probability of less than 10 per cent, none of these had sites. Another 8 hectares had site probabilities between 17 and 36 per cent, one large site extended over 5 of these. The remaining three hectares were either next to the river or on a soil type with a very high site association and were assigned a 100 per cent probability. None of these contained sites, however. Altogether the model predicted that 4.73 hectares would contain sites and 5 did (Solis and Futato 1987:91-92). These results were promising, but very preliminary. In this present paper we will discuss a larger test of the model, based on the survey work done in the Guntersville Lake area.

A TEST OF THE MODEL

Guntersville Lake lies within the Sequatchie Valley of extreme northeastern Alabama (Figure 1). The Sequatchie Valley is an eroded anticline (Johnston 1930) which forms a limestone based valley extending approximately 160 km into Alabama and averaging some 8 km wide here. The eastern boundary of the valley in our study area is formed by the escarpment of Sand Mountain. Sand Mountain is a sandstone capped plateau which rises over 250 m in elevation over a distance of less than a kilometer. The Jackson County Mountains lie west of the Sequatchie Valley here. The Jackson County Mountains are a submaturely dissected region of the same plateau which makes up Sand Mountain, consisting of mesas rising 250-300 m above the limestone valleys which separate them. The Tennessee River flows south-southwest through this portion of the Sequatchie Valley. Sand Mountain to the east and more resistant formations forming ridges along the valley floor to the west have restricted the river to a relatively straight, narrow alluvial valley lacking a wide flood plain or meander belt. The channel of the Tennessee River is 500 m wide here, and the entire alluvial valley is only 1200-1500 m wide.

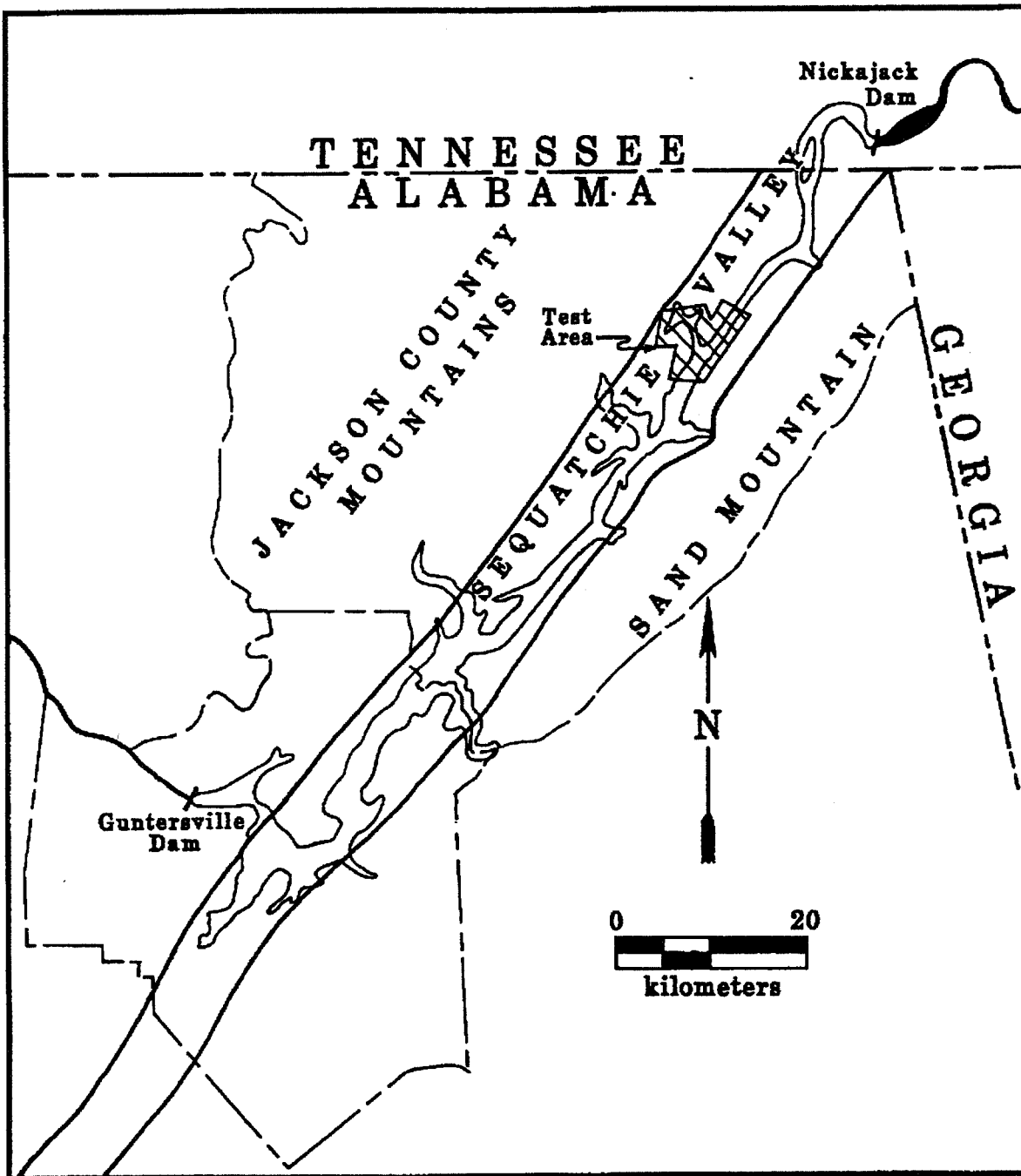


Figure 1. Guntersville Lake within the Sequatchie Valley.

The University of Alabama surveyed 13,600 ha of Federally-owned land along Guntersville Lake for the Tennessee Valley Authority during four seasons of survey from 1983 to 1986. One product of this research was a site distribution model developed by the method outlined above. The details of the model and the resulting interpretations of site distribution were presented in the project report (Solis and Futato 1987: 77-109) and will not be repeated here. Instead, we will apply the model to a selected portion of the survey area to provide a further test of the model's ability to predict site locations.

The area chosen for this test of the model consists of several adjacent survey tracts in the vicinity of Stephenson, Alabama (Figure 1). These survey tracts were not subjected to a 100 percent survey

coverage in the Guntersville survey and so were not used in the model development. But all tracts were minimally surveyed to such an extent that we were confident that all prominent or significant sites were located and that all high site probability areas were examined. Most of tracts in the chosen test sample were relatively high priority areas, and 95 percent or more of the total area was surveyed. Numerous sites were located. Moreover, the tracts include the range of environments represented in the original model. The original analysis was stratified using the assignment of soil types to general soil series, and separate models were generated for: bottoms, terraces, limestone valley uplands, colluvial slopes (at the foot of ridges and mountains), and rocky slopes (on the mountainsides). The selected test area includes extensive bottom land and terrace areas, and a smaller sample of the valley uplands. Altogether, the chosen test area is considered appropriate because:

1. It was not used in the model development and will serve as an independent test of the model,
2. It was surveyed at a level of thoroughness such that we are reasonably confident that all or virtually all of the sites present were recorded,
3. And it includes a broad range of the environments represented in the model.

In all, the test area contained 889 hectares. Of these, 478 were in the bottoms, and 75 of these contained sites; 359 were on the terraces, 84 of these contained sites; and the remaining 52 were in the uplands, 5 of these contained sites.

The model test was conducted in the usual way. First, the five environmental variables and the presence or absence of an aboriginal site were recorded for each hectare in the test area. Then the relative site frequency scores from the original models were assigned to each attribute state and the mean score was calculated for each hectare. The probability of site occurrence for each hectare was then taken from the site probability tables in the original model. Then the accuracy of the predictions was evaluated.

In simplest terms, we can say that the failure of the model to predict site locations was almost complete. On the basis of either mean hectare score or site probability, hectares with and without sites were almost completely indistinguishable as shown below:

		Hectares With Sites	Hectares Without Sites
Bottoms:	Mean Hectare Score	1.2	0.9
	Mean Site Probability	13	9
Terraces:	Mean Hectare Score	1.1	1.1
	Mean Site Probability	11	12
Uplands:	Mean Hectare Score	2.2	2.4
	Mean Site Probability	60	29

In fact, the non-site hectares in the uplands actually had a higher mean hectare score than did the site hectares. The mean site probability is lower even though the score is higher because hectare scores above 1.3 were infrequent in the original model and most site probability figures were interpolated

between hectare scores with either 0 or 100 percent site probability.

Clearly the failure of the model to predict site locations in the test area requires some explanation. Some of the error is no doubt due to sampling error resulting from the small size of the original sample. A major portion of the error, however, is due to the fact that site locations in the test area simply do not conform to the site locations which were used in the original model.

The test data were used to generate an independent model of site distribution in the test area. Since data on all hectares was recorded, the actual frequencies of environmental attribute states were used, rather than an estimate based on a 25 percent sample. Otherwise, the methods were identical to those of the initial model. Tables 3-5 present the relative site frequencies for the two models and it can be seen that the site distributions are distinct. Some soil types, water sources, etc. which were important site locations in the original sample first model have almost no sites in the test sample, and vice versa.

Some of this may be due to sample error, but a number of possible archaeological or environmental explanations for these differences could also be explored. There may be cultural, temporal, and/or functional differences between the respective site groups but our current understanding of the occupation of the region suggests this should not be a major factor. More likely, the site distribution patterns in the vicinity of the test tracts truly are distinct from those elsewhere in the Guntersville Basin area. The model was primarily developed using data from the lower and middle reservoir areas, taken mainly from areas generally between River Miles 349-365 and 388-394, respectively. The test area is farther upstream, River Miles 397-404. Further analysis may show distinct subregional differences in site distribution along this 50 mile stretch of the river.

SUMMARY

One purpose of this paper was to present a particular method of modeling archaeological site locations and to test the ability of a model produced by this method to predict site locations in a selected test area. The original model provided an intuitively satisfying and apparently reasonable account of site distribution. This model failed, however, to predict site locations in the chosen test area. Observed patterns of site distribution in the test area are quite different from those in the original model. The test area is farther upstream than those areas from which the original model was developed, suggesting that local differences in site distribution may account for the discrepancy. Sample error in the original model data is another possible explanation.

But another purpose of this paper has been to demonstrate that GIS-type analyses need not be limited to researchers who have access to sophisticated equipment and software. If the problem is of an appropriate nature and scope, the principles of GIS-type analysis can be applied to solving that problem using whatever means are available to the researcher. The author hopes that in that regard this paper may have been more successful.

Table 3. Comparison of Relative Frequencies of Variable States in the Bottom Lands.

VARIABLE STATE	GUNTERSVILLE BASIN MODEL	TEST AREA MODEL
SOIL TYPE:		
Bruno Fine Sandy Loam	2.8	1.4
Egam Silt Loam	0.0	2.2
Egam Silty Clay Loam	0.2	NA
Egam-Newark Silty Clay Loams	2.4	NA
Huntington Fine Sandy Loam	3.7	NA
Huntington Silt Loam	2.8	1.3
Lindside Silt Loam	0.9	1.0
Lindside Silty Clay Loam	0.0	0.3
Melvin Fine Sandy Loam	0.0	NA
Melvin Silt Loam	0.0	0.4
Melvin Silt Loam and Silty Clay Loam	0.0	NA
Melvin Silty Clay Loam	NA	0.4
Newark Loam	99.9	NA
WATER SOURCE:		
First Order	0.8	0.6
Second Order	0.0	1.0
Third Order	0.0	0.3
Major Tributary	0.0	1.0
River	3.9	1.7
DISTANCE TO WATER:		
1-100 m	1.3	1.4
101-200 m	0.4	0.9
201-300 m	0.6	0.7
301-400 m	0.0	0.6
401-500 m	99.9	0.0
500+ m	0.0	0.0
ELEVATION:		
560 ft	0.0	NA
580 ft	1.2	NA
600 ft	1.0	0.9
620 ft	0.0	1.7
RELIEF:		
0	1.0	1.0
20 ft	1.8	0.0
40 ft	NA	0.0
60 ft	0.0	NA
80 ft	0.0	NA

NA = Not Applicable

Table 4. Comparison of Relative Frequencies of Variable States in the Terraces.

VARIABLE STATE	GUNTERSVILLE BASIN MODEL	TEST AREA MODEL
SOIL TYPE:		
Capshaw Silt Loam	0.0	1.6
Captina Silt Loam	0.5	NA
Cumberland Loam	0.0	NA
Cumberland Silt Loam	0.0	0.0
Cumberland Silty Clay Loam	1.3	0.2
Etowah Loam	3.9	1.6
Etowah Silt Loam	2.2	1.2
Etowah Silty Clay Loam	0.0	2.2
Holston Loam	0.3	0.9
Monongahela Fine Sandy Loam	0.0	NA
Robertsville Silt Loam	0.0	0.0
Robertsville Silty Clay Loam	0.7	NA
Sequatchie Fine Sandy Loam	9.8	0.3
Taft Silt Loam	0.0	0.0
Tupelo Silt Loam	0.0	0.4
Tyler Fine Sandy Loam	0.0	NA
Tyler Very Fine Sandy Loam	0.0	0.0
Waynesboro Fine Sandy Loam	0.0	1.4
Waynesboro Loam	NA	0.0
Wolftever Silt Loam	3.7	2.4
WATER SOURCE:		
Spring	0.0	NA
First Order	0.6	1.2
Second Order	1.2	1.3
Third Order	0.9	0.7
Major Tributary	1.9	0.5
River	5.6	2.0
DISTANCE TO WATER:		
1-100 m	0.3	1.1
101-200 m	1.7	1.2
201-300 m	1.5	1.2
301-400 m	1.2	0.6
401-500 m	0.6	0.6
501-600 m	0.7	0.7
600+ m	0.3	0.0

Table 4. (Continued.)

VARIABLE STATE	GUNTERSVILLE BASIN MODEL	TEST AREA MODEL
ELEVATION:		
580 ft	1.4	NA
600 ft	0.8	0.8
620 ft	1.9	1.5
640 ft	1.4	0.0
660 ft	0.0	0.0
RELIEF:		
0	1.0	1.0
20 ft	1.2	0.3
40 ft	0.9	0.0
40+ ft	NA	0.0

NA = Not Applicable

Table 5. Comparison of Relative Frequencies of Variable States in the Uplands.

VARIABLE STATE	GUNTERSVILLE BASIN MODEL	TEST AREA MODEL
SOIL TYPE:		
Armuchee Silty Clay Loam	0.0	NA
Armuchee-Tellico Silty Clay Loams	0.0	NA
Clarksville Cherty Silt Loam	99.9	NA
Colbert Silty Clay	0.0	NA
Colbert Silty Clay Loam	0.0	4.2
Dewey Cherty Silt Loam	0.0	NA
Dewey Silt Loam	NA	0.0
Dewey Silty Clay Loam	6.6	0.0
Fullerton Cherty Silt Loam	1.4	0.8
Fullerton Silty Clay Loam	0.0	NA
Fullerton-Clarksville Cherty Silt Loams	0.0	NA
Montevallo Shaly Silt Loam	0.0	NA
Talbott Silt Loam	0.0	NA
Tellico Clay Loam	0.0	NA
Tellico-Upshur Soils	0.0	NA

Table 5. (Continued.)

VARIABLE STATE	GUNTERSVILLE BASIN MODEL	TEST AREA MODEL
WATER SOURCE:		
First Order	1.1	0.0
Second Order	0.0	0.0
Third Order	3.9	0.0
Major Tributary	0.0	5.2
River	0.0	1.2
DISTANCE TO WATER:		
1-100 m	2.2	0.0
101-200 m	1.2	0.8
201-300 m	0.9	3.5
301-400 m	1.7	1.5
401-500 m	0.0	0.0
500+ m	0.0	0.0
ELEVATION:		
600 ft	12.5	0.0
620 ft	3.3	1.8
640 ft	0.0	0.0
660 ft	0.0	0.0
660+ ft	0.0	0.0
RELIEF:		
0	5.6	2.1
20 ft	0.7	0.0
40 ft	0.0	0.0
60 ft	0.0	0.0
80 ft	0.0	0.0
80+ ft	0.0	0.0

NA = Not Applicable

REFERENCES

Johnston, William D., Jr. 1930. Physical Divisions of Northern Alabama. Geological Survey of Alabama, Bulletin 38. University.

Solis, Carlos, and Eugene M. Futato 1987. Cultural Resource Investigations in the Guntersville Reservoir Area, Marshall and Jackson Counties, Alabama and Marion County, Tennessee. Report submitted to the Tennessee Valley Authority, Norris by the University of Alabama, Alabama State Museum of Natural History, Office of Archaeological Research, University. University of Alabama, Alabama State Museum of Natural History, Office of Archaeological Research, Report of Investigations 48. University.

SETTLEMENT PATTERNS, GIS, REMOTE SENSING AND THE LATE PREHISTORY OF THE BLACK PRAIRIE IN EAST CENTRAL MISSISSIPPI

Jay K. Johnson*

56-43
201793
p. 10

ABSTRACT

Data recovered as the result of a recent field project designed to test a model of the distribution of protohistoric settlement in an unusual physiographic zone in eastern Mississippi are examined using GIS based techniques to manipulate soil and stream distance information. Significant patterning is derived. The generally thin soils and uniform substratum of the Black Prairie in combination with a distinctive settlement pattern offer a promising opportunity for the search for site specific characteristics within airborne imagery. Landsat TM data provide information on modern ground cover which is used as a mask to select areas in which a multivariate search for archeological site signatures within a TIMS image is most likely to prove fruitful.

INTRODUCTION

We are in the final analysis phase of a project which was designed to test a model of late prehistoric/ Protohistoric settlement in the Black Prairie, a distinctive physiographic zone in northeast Mississippi. The original settlement model was based on data recovered during two cultural resource management projects and a state funded county survey and was conducted before Geographic Information Systems (GIS) and remote sensing capabilities were part of the research facility at the Center for Archaeological Research, University of Mississippi. The current project has relied extensively on these techniques and the resulting refinement of the settlement model is methodologically interesting.

The Black Prairie was formed upon a geologically distinctive deposit of chalk which has resulted in a relatively more eroded, rolling plain bounded on the east and west by sands and clays (Stephenson and Monroe 1940). The first of the cultural resource management projects in the area focused on a series of proposed reservoirs and canalization projects in the Line Creek watershed which drains across the prairie in the vicinity of West Point, Mississippi (Johnson et al. 1984). The project included several physiographic zones in addition to the Black Prairie and we resorted to the original general land office witness tree data in order to evaluate existing forest type characterizations for the region (Lowe 1911; Kuchler 1964).

Ten townships were selected forming a rectangular area roughly 40km east-west and 20km north-south. The location of each witness tree within the area was recorded using the data contained in the notes. That is, the sections which the line bounded and the distance from the corner which was being used as a point of origin were entered into a data file. Distance was recorded in chains and links. A FORTRAN program was written which converted the distances to miles and located each tree in a Cartesian coordinate system using the southwest corner of the township as a point of reference. The tree locations and tree types for all ten townships were then combined in a master file

*Department of Sociology and Anthropology, University of Mississippi.

using a common coordinate system with an origin in the extreme southwest of the survey area. This file included the names and coordinates of 1551 trees located within the one mile grid dictated by their location along section boundaries.

As a next step, the survey area was overlaid with a half mile grid whose origin corresponded with the origin for the tree data file. Eight major physiographic zones were delineated ranging from the North Central Hills in the west to the Black Prairie in the east, all of which were crosscut by stream bottoms and Pleistocene terraces. The location of the grid points within the zones was determined by recording the points at which a transition into a different zone occurred for each of 30 east-west transects spaced at half mile intervals. The data matrix was filled out using a FORTRAN program which assigns each data point in the half mile grid to a zone on the basis of the boundary locations.

The tree location file and the physiographic zone file were then compared using a third program which computes the distance between each tree and every point and the physiographic zone file and assigned it to the closest. The witness tree composition of each zone was evaluated by comparing observed (actual proportion of each tree in a specific zone) and expected (proportion of that tree in the overall sample) values (Johnson et al. 1984:Table 2-1). This made it possible to make a start toward characterizing resource availability in each zone.

Sites were assigned to physiographic zone and soil type on the basis of map inspection and tables showing breakdown by chronological phase assignment and site setting were examined for patterns (Johnson et al. 1984:Tables 3-3, 3-4). Since the majority of the survey was within reservoir boundaries, it was possible to compute site density in terms of sites per square mile for each of the physiographic zones (Johnson et al. 1984: Table 3-6). This also revealed interesting patterning. At this point it was clear that Protohistoric sites showed a preference for thin, upland soils in the Black Prairie, a site setting which is almost unique to this time period since the majority of the Protohistoric sites in the Line Creek sample are single component (Johnson 1988).

The Line Creek survey was followed by two other research projects in the Black Prairie, a CRM survey of Chuquatonche Creek to the north (Johnson and Curry 1984) and a master's thesis on material collected during a county-wide survey conducted by the Mississippi Department of Archives and History (Sparks 1987). Both allowed a refinement of the Protohistoric settlement model and both show the limitations of pre-GIS settlement pattern studies. Chuquatonche Creek is located entirely within the Black Prairie and we had predicted a large number of Protohistoric sites prior to the survey. We found only one. This was related to a lower stream flow in the Chuquatonche drainage (Johnson and Curry 1984). Sparks (1987) dealt with a much more extensive but less systematic sample from Clay County, Mississippi, the county which contains most of the Line Creek survey area. He found similar patterning in the distribution of Protohistoric settlement, particularly with reference to physiographic zone. A preference for thin, upland prairie soils was documented by comparing the observed frequency of sites within this zone to the expected as computed using the overall breakdown of the entire county presented in the county soils map. There are some serious methodological problems with this approach but it was the only one available given the nature of the sample and the limitations of settlement pattern analysis prior to the introduction of GIS.

Sparks and I joined our data to present an overview of Protohistoric settlement in the middle portion of the Black Prairie (Johnson and Sparks 1986). Two additional factors were included in this analysis, stream bottom soil texture class and stream order. Protohistoric sites were located

predominantly on second order streams (Johnson and Sparks 1986:Table 5.3). Stream order assignment was determined in terms of nearest stream through map inspection. The differences in site density between the Line Creek and Chuquantonche sample was further explained on the basis of generally coarser sediments in the Line Creek survey area (Johnson and Sparks 1986:Tables 5.6, 5.7). The proportion of each reservoir made up by each texture class was determined by using a point counter and the county soils maps.

So, at the conclusion of these three projects a clear picture of Protohistoric and the preceding Mississippian settlement pattern had developed, allowing a consideration of the radical shift in site locational strategy which was involved. Middle Mississippian sites in the region are almost exclusively located on the terraces of the major streams. They are often quite large and some contain platform mounds. Protohistoric sites, on the other hand, are typically located on narrow upland ridges extending out into the bottoms of the smaller streams which drain the prairie. A preference for stream bottoms with coarser sediments presumably relates to a greater potential in terms of agriculture. Protohistoric sites are generally quite small.

While the outlines of the Protohistoric settlement distribution were easy to see, the model was more qualitative than quantitative and there seemed to be the potential for more detail. Consequently, proposals were submitted to the National Geographic Society and the National Endowment for the Humanities and funding was secured for a joint project of the Mississippi Department of Archives and History and the University of Mississippi in order to conduct fieldwork directed toward expanding our knowledge of the nature and timing of the Protohistoric move into the prairie uplands. During the months of June, July and August 1989, a five-man field crew completed the field work phase of the project. First, a 33% sample of the area along two east-west transects in the region of West Point, Mississippi, was searched for sites. A total of 3305 hectares were surveyed using a 30m interval for pedestrian transects. Shovel testing was employed in areas where vegetation covered the ground surface. Once a site was located, shovel testing and surface collecting were used to secure a sample of artifacts. We now have collections from 110 sites, 90 of which were previously unknown. More than half, 64, of these sites contain shell tempered pottery. The vast majority of these sherds are plain. Only four of the shell tempered assemblages can be assigned to a specific phase, one Middle Mississippian and three Protohistoric.

For the purposes of the following analysis of Protohistoric settlement, all sites containing Protohistoric ceramics or shell tempered ceramics with no Middle Mississippian markers were considered potential Protohistoric sites. The locations of these sites were digitized and patterns in their distribution relative to soils and streams were examined using a PC based GIS software known as ERDAS. The three data planes which will be discussed were recorded at a 30m resolution. The basic operation in a GIS analysis consists of overlaying two or more data planes and examining patterns in the coincidence of features of interest. For example, Table 1 shows the total Protohistoric site area in our survey sample broken down by soil type in the column marked "Observed." The next column to the right shows the percentage of the total survey area made up by each of the soil types. If sites were located randomly in relation to soils, this would be the expected proportion of the site acreage to be made up by that soil.

It should be emphasized that the expected proportions are derived by digitizing the areas which were actually surveyed. In effect, this compensates for biases in the sample since the exact composition of the survey area can be computed in terms of any variable of interest. This can be particularly useful when a landscape feature is discovered to be of importance after the sample has been drawn.

Although the sample may be in no way representative in terms of this variable, its proportional breakdown within the sample can be determined and deviations from random in the distribution of sites can be examined.

This procedure has obvious parallels in analyses which were done with the Protohistoric data prior to GIS and could have been done with the Line Creek data using a point counter. Futato (1989) has done a similar analysis without GIS capabilities. However, the labor involved is prodigious.

There are interesting differences between the observed and expected values in Table 1 which can easily be expressed in terms of the observed to expected ratio. When this value exceeds one, sites occur in frequencies which are higher than expected for that particular soil type. All but one (cpo) of the soils for which this condition holds in Table 1 are upland soils. Moreover, 7 of the 9 soils for which the O/E ratio exceeds 2.0 are shallow upland prairie soils.

This obvious selection during the Protohistoric for shallow upland soils in the Black Prairie comes as no surprise, confirming as it does a pattern noted in earlier research (Johnson and Sparks 1986). Furthermore, a recent, preliminary analysis of historic Chickasaw settlement in the Tupelo region (Johnson et al. 1989) has demonstrated that not only are the shallow soils likely locations for settlement, the areas in the vicinity of the shallow soils show concentrations of

settlement. Therefore, a proximity analysis of the Clay County survey data was performed (Table 2). In GIS, this is done by projecting distance contours around each occurrence of the area in question, in this case, shallow prairie soils. The contour interval is fixed at 30m since that is the resolution of the data. The O/E ratio for all shallow soils is a relatively high 3.09 with a drop to 1.60 in the area within 30m and subsequent drop-off in the next zone, beyond which the ratio is less than one. There is clear patterning here. However, 48.6% of the site area falls beyond the 300m contour. Consequently, a proximity analysis was conducted for deep prairie soils (Table 3). The O/E ratio for the combined deep soils is much lower than that for shallow soils and there is much less patterning in the distance contours.

Table 1. Protohistoric site area broken down by soil

Soil Type	Observed %	Expected %	O/E
cod	8.10	1.81	4.48
sub2	8.38	2.58	3.25
svb2	3.63	1.18	3.08
klb2	2.23	0.73	3.05
bnb	4.47	1.53	2.92
oka	7.26	2.65	2.74
sub21	1.12	0.52	2.15
svc2	5.59	2.66	2.10
sud2o	0.84	0.42	2.00
gse	2.23	1.50	1.49
kpb2	23.46	15.80	1.48
okb	7.82	5.36	1.46
vab2	0.84	0.71	1.18
cpo	3.35	3.07	1.09
un	0.84	1.09	0.77
kpc2	2.79	4.14	0.67
bra	0.84	1.51	0.56
suc2	1.12	2.02	0.55
kia	0.28	0.58	0.48
gr	3.63	7.65	0.47
le	7.82	16.56	0.47
kpa	1.68	4.25	0.40
brb	1.12	2.95	0.38
cpl	0.00	0.03	0.00
klc2	0.00	0.03	0.00
loa	0.00	0.07	0.00
ote3	0.00	0.20	0.00
vac2	0.00	0.23	0.00
ord2	0.00	0.37	0.00
svd3	0.00	0.44	0.00
oz	0.00	0.57	0.00
mha	0.00	0.62	0.00
lel	0.00	0.64	0.00
orc2	0.00	0.77	0.00
vaa	0.00	0.84	0.00
sre	0.00	0.90	0.00
be	0.00	1.28	0.00
orb	0.00	3.49	0.00
se	0.00	3.85	0.00
tl	0.00	4.40	0.00

Table 2. Protohistoric site area broken down by proximity to shallow prairie soils.

Zone	Observed %	Expected %	O/E
shallow soils	30.17	9.75	3.09
30m	8.94	5.59	1.60
60m	3.63	3.32	1.09
90m	2.51	2.52	1.00
120m	2.51	2.77	0.91
150m	1.40	1.64	0.85
180m	1.12	1.68	0.67
210m	0.56	1.28	0.43
240m	0.28	1.27	0.22
270m	0.56	1.35	0.41
300m	0.28	0.97	0.29
>300m	48.04	67.85	0.71

Table 3. Protohistoric site area broken down by proximity to deep upland soils.

Zone	Observed %	Expected %	O/E
deep soils	38.55	23.78	1.62
30m	7.54	9.80	0.77
60m	4.19	6.06	0.69
90m	5.87	4.96	1.18
120m	6.70	5.47	1.22
150m	1.96	2.97	0.66
180m	1.96	2.88	0.68
210m	1.40	2.03	0.69
240m	0.56	1.94	0.29
270m	0.56	1.94	0.29
300m	0.84	1.32	0.64
>300m	29.89	36.86	0.81

Table 4. Sites cross-tabulated by order of nearest stream and phase assignment.

	Stream Order					
	First	Second	Third	Fourth	Fifth	Sixth
Earlier	O= 9.0 E=16.2	O= 9.0 E= 7.7	O= 0.0 E= 0.9	O=10.0 E= 4.7	O= 2.0 E= 1.7	O=17.0 E=15.8
Protohistoric	O=29.0 E=21.8	O= 9.0 E=10.3	O= 2.0 E= 1.1	O= 1.0 E= 6.3	O= 0.0 E= 2.3	O=20.0 E=21.2

Table 5. Protohistoric site area broken down by proximity to first order streams.

Zone	Observed %	Expected %	O/E
stream	0.84	2.72	0.31
30m	4.19	6.97	0.60
60m	4.47	5.19	0.86
90m	6.42	5.10	1.26
120m	10.89	7.41	1.47
150m	7.82	5.18	1.51
180m	8.10	6.06	1.34
210m	5.03	4.93	1.02
240m	4.47	5.28	0.85
270m	3.91	5.70	0.69
300m	4.75	4.08	1.16
>300m	39.11	41.38	0.95

Table 6. Protohistoric site area broken down by proximity to second order streams.

Zone	Observed %	Expected %	O/E
stream	0.00	1.00	0.00
30m	0.28	2.72	0.10
60m	1.12	2.02	0.55
90m	3.07	2.07	1.48
120m	7.26	3.20	2.27
150m	6.70	2.32	2.89
180m	5.03	2.93	1.72
210m	2.23	2.52	0.88
240m	2.51	2.81	0.89
270m	1.96	3.29	0.60
300m	0.84	2.55	0.32
>300m	68.99	72.57	0.95

Again, this could have been done without GIS capabilities using a point counter but we are now getting into an extremely labor intensive analysis. In GIS, since the soils had already been digitized all it cost was some computer time. Without GIS you would have to return to the maps every time you wanted to consider a new set of variables in the proximity analysis.

Also, GIS allows relationships between landscape features in the same data plane to be examined. The relatively low O/E for deep upland soils and the lack of patterning in the proximity analysis suggest that these soils are not as important in settlement modeling as the shallow soils. Perhaps sites were located only on deep soils in the proximity of shallow soils. This proposition can be tested by overlaying a file in which deep soils are distinguished and one in which shallow soils with distance contours have been generated. Of the 38.55% of the survey area which was classified as a deep upland soil, 7.06% (about 1/5) falls within 300m of shallow soils with 3.10% occurring within the first 60m and containing 5.87% of the total site area. Adjacent shallow soil plays a role in the distribution of sites within deep soils; however, 16.72% of the site area located on deep soils falls beyond the 300m distance contour from shallow soils.

In an effort to refine the pattern, a data plane was created which specified areas which were deep upland soils or shallow upland soils or within 60m of shallow upland soils. This accounted for 35.38% of the survey area and accounted for 73.46% of the Protohistoric site area, yielding a quite respectable O/E of 2.08.

Still, we know from earlier work (Johnson and Sparks 1986) that another factor, stream order, was critical in the location of Protohistoric sites. Accordingly, streams were classified and digitized and sites were classified as to closest stream order. A cross-tabulation of sites by time and stream order of nearest water (Table 4) shows that more than half, 38, of the sites with Protohistoric components are located high in the drainages nearest a first or second order stream. And, the observed values for these cells exceed the expected. Proximity analyses of first and second order stream locations (Tables 5, 6) show definite patterning. Moving away from the streams, O/E exceeds 1.0 at 60m in both cases, confirming the fact that sites are not located in these relatively narrow bottoms but on the bluffs overlooking them. There follows a roughly symmetrical increase and then drop-off until the O/E approaches 1.0 at about 210m for first order and 180m for second order streams. These bands paralleling first and second order streams on both sides constitute 36.43% of the survey area and contain 49.72% of the site area. The O/E ratio of 1.36 is lower than that obtained in the final soils analysis.

Combining stream and soil data, a final data layer was created which specified all the area which was deep upland soil or shallow upland soil or within 120m of shallow upland soil and 90 to 210m of a first order stream or 90 to 180m of a second order stream. This ability to create synthetic data planes using Boolean logic is a powerful aspect of GIS analysis. The resulting zone amounted to 15.07% of the survey area and accounted for 39.94% of the site area with an O/E of 2.65. This balances the need to maximize both the amount of site area included and the O/E.

This conclusion nicely illustrates the value of GIS in settlement pattern analysis, its iterative nature. Starting with three data planes, trial combinations can be explored, modified or rejected until the optimal combination of factors is reached. Analyses which took weeks using a GIS would take months otherwise, if they were done at all.

This project was also designed to test the possibility that we may be able to move beyond a general characterization of site locations to actual detection of the sites themselves. Recent analysis of data recovered using TIMS sensor over the Poverty Point site in eastern Louisiana has suggested that soil conditions which are characteristic of human habitation, primarily phosphate concentration, have a sufficiently strong signature to be detected on a regular basis (Gibson 1984; Sever and Wiseman 1985). If this proves true in the Protohistoric survey area, we may actually be able to map the locations of the sites from the air despite the fact that they show no obvious surface expression.

Accordingly, the survey sample was chosen to coincide with two flight lines which were recorded by a NASA flight crew this summer using a TIMS sensor. The data were collected at a 5m resolution. Two things became immediately evident as I worked with TIMS data for the first time. The first is the difference in the amount of disk space required to work with satellite data and aircraft data. The same amount of area requires 36 times the amount of storage as it did for Landsat data. The 80 meg hard drive which has been reserved for data files on our PC based system became instantly inadequate. The second difference is in georeferencing. Where three or four ground control points per map were sufficient with the relatively stable satellite platform, fifteen or twenty were needed to correct the distortion caused by aircraft movement. The task was too much for ERDAS version 7.2 and had to be conducted at the NASA facility at Stennis. It took four days to georeference a line 12.2km long and 3.7km wide. While all of this should have been anticipated, you have to experience it to believe it.

Once the processing was completed, initial inspection of the imagery was encouraging. The area around the plaza edges at Lyons Bluff, a large Middle Mississippian to Protohistoric site on the Black Prairie (Marshall 1986), shows a distinctive, relatively high return for channel 4. A scan of other site locations along the flightline with similar ground cover (pasture and scrub) show similar spectral characteristics. Therefore, a GIS file was built which consisted of all digitized sites which were located in areas designated as pasture or scrub vegetation on the basis of Landsat TM data for the region. Ground cover classification of the satellite imagery was produced by running an unsupervised classification of the 30m data from an April 1984 scene. The resulting 27 classes were assigned to one of six broad categories (water, agricultural field, scrub vegetation, pasture, pine, hardwood) on the basis of map inspection and spectral characteristics as displayed in bivariate plots of the cluster means. The GIS file was then resampled to a file with 5m resolution whose origin and size matched the georeferenced TIMS data. A visual inspection of the ground cover file overlaying the image file showed a close correspondence between tree lines, roads, rivers and other features of the landscape, lending confidence to the georeferencing of both the satellite and aircraft data. Finally a composite GIS file was created which designated those areas which were known archaeological sites and were also classified as either pasture or scrub in the land cover file.

This file was used as a mask to isolate those areas in the six band TIMS data. All of the remaining area in the scene was set to zero. An unsupervised classification using a Mahalanobis distance measure produced initially encouraging results when only three clusters were distinguished, suggesting relative homogeneity for these site locations. When these signatures were applied to the portion of the scene which had been surveyed, no apparent patterning resulted. This was not surprising since each pixel was forced into one of these three groups regardless of how different it is. However, when probability thresholds were used to refine the classification, it became evident that there was no relationship between site locations and these classes. For example, using a chi-square value of 4, 68.45% of the scene remains unclassified and contains 63.86% of the site area. Sites are slightly less

likely to occur in the unclassified areas than they would by chance alone. A chi-square of 4 yields a confidence level of about .70 with 6 band data but threshold results were not evaluated on this basis. Once again, maximizing the observed to expected ratio for site area was the objective. Different chi-square values were used to slide the classification threshold but no improvement was achieved.

Therefore, the Lyons Bluff site was used as a training field in a supervised classification. This is accomplished by displaying the portion of the scene where the site is located and using a joy stick to draw polygons around the areas in the plaza where midden deposits are reported to occur and appear to be giving a distinctive return in the TIMS imagery.

Actually, three different polygons were evaluated, all of which gave about the same mean values on the six bands. The area with the lowest coefficients of variation was selected on the assumption that this would provide the most distinctive signature with which to distinguish site area. This signature was used in classifying the rest of the survey area using Mahalanobis distance again. Since this measure makes use of the covariance matrix in evaluating group membership, the homogeneity of the training field meant that the confidence levels used in the threshold procedure had to be relaxed considerably. For example, a chi-square of 10 (confidence level of about 0.13) included only 1.03% of the survey area within the Lyons Bluff class and this class included only 1.23% of the site area. Although the O/E ratio is greater than 1, it is not by much. Increasing the chi-square to 20 (confidence level of less than 0.005) relaxes the group inclusion criterion to classify 6.48% of the survey area encompassing 7.89% of the site area. This improves the O/E ratio but only slightly and the results are nowhere near as satisfactory as those derived from the GIS analysis based upon soils and stream order.

At this point, the attempt to derive site specific signatures from remote imagery remains frustrated. However, the analysis will continue. We have dealt only with a portion of the imagery. A larger sample will allow us to be more selective in the kinds of site settings we examine. Because of the limitations of a PC based system, we have used raw values rather than imagery corrected for atmospheric conditions. The redundancy in the TIMS data resulting from between band correlation can be reduced through principal components analysis and this may improve both supervised and unsupervised classification. In other words, it won't be easy but there are still possibilities to explore in the TIMS data set. We need to remember that we are dealing with the result of actions which occurred more than 500 years ago in a culturally and biologically active environment.

On the other hand, the GIS analysis has demonstrated, once again, the value of this tool in settlement pattern analysis. Not only does it allow the precise evaluation of the relationship between site locations and several different kinds of geographic data, the rapid feedback and facility with which data planes can be combined, which is part of GIS, make it easy to explore successively more sophisticated hypotheses about these relationships. The only significant limitation is the time and expense involved in digitizing the data planes. And as more and more people, especially governmental agencies, begin to use GIS, the range of data available in digitized format will increase. The marriage of archaeology and GIS is a natural one which is bound to flourish.

ACKNOWLEDGEMENTS

I would like to recognize the tremendous hospitality of the people of Clay County among whom Rufus Ward stands out. Tom Sever, a NASA archaeologist at the Stennis Space Center, has played an essential role in the acquisition and processing of the TIMS data as well as in my development as a remote sensor. Harry Hoff, an operator for Lockheed, has been the one who sat with me in the dark watching a blinking cursor as we wrestled with tapes, disk packs and ground control points. This was a joint University of Mississippi-Mississippi Department of Archives and History project with funding provided by the National Geographic Society and the National Endowment for the Humanities, an independent government agency.

REFERENCES

- Futato, E.M. 1989. An archaeological overview of the Tombigbee River Basin, Alabama and Mississippi. University of Alabama. State Museum of Natural History. Division of Archaeology. Report of Investigations 59.
- Gibson, J.L. 1984. The Earthen Face of Civilization: Mapping and Testing at Poverty Point 1983. Louisiana Division of Archaeology.
- Johnson, J.K. and H.K. Curry. 1984. Final Report, Cultural Resources Survey in the Chuquatonchee Creek Watershed, Chickasaw, Clay, Monroe and Pontotoc Counties, Mississippi. Center for Archaeological Research, University of Mississippi, Report submitted to Soil Conservation Service, Jackson, Mississippi, Contract No. 53-4423-3-439.
- Johnson, J.K., H.K. Curry, J.R. Atkinson and J.T. Sparks. 1984. Final Report, Cultural Resources Survey in the Line Creek Watershed, Chickasaw, Clay and Webster Counties, Mississippi. Center for Archaeological Research, University of Mississippi, Report submitted to the Soil Conservation Service, Jackson, Mississippi. Contract No. 53-4423-2-314.
- Johnson, J.K. P.K. Galloway and W. Belokon. 1989. Historic Chickasaw settlement patterns in Lee County, Mississippi: A first approximation. Mississippi Archaeology 24(2):45-52.
- Johnson, J.K. and J.T. Sparks. 1986. Protohistoric Settlement Patterns in Northeastern Mississippi. In The Protohistoric Period in the Mid-South: Proceedings of the 1983 Mid-South Archaeological Conference, edited by D.H. Dye and R. C. Brister, PP.64-82. Mississippi Department of Archives and History, Archaeological Report 18.
- Kuchler, A.W. 1964. Potential Natural Vegetation of the Conterminous United States. American Geological Society, Special Publications No. 36.
- Lowe, E.N. 1911. Soils of Mississippi. Mississippi State Geological Survey, Bulletin 8.

Peebles, Christopher S. 1987. The Rise and Fall of the Mississippian in Western Alabama: The Moundville and Summerville Phases, A.D. 100 to 1600. Mississippi Archaeology 22(1):1-31.

Sever, T.L. and J. Wiseman. 1985. Remote Sensing and Archeology: Potential for the Future. National Aeronautics and Space Administration, Earth Resources Laboratory.

Sparks, J.T. 1987. Prehistoric Settlement Patterns in Clay County, Mississippi. Mississippi Department of Archives and History, Archaeological Report 20.

Stephenson, L.W. and W.H. Monroe. 1940. The Upper Cretaceous Deposits. Mississippi State Geological Survey, Bulletin 40.

APPLICATIONS OF ECOLOGICAL CONCEPTS AND REMOTE SENSING TECHNOLOGIES IN ARCHAEOLOGICAL SITE RECONNAISSANCE

W. Frank Miller*, Thomas L. Sever**, Daniel Lee***

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

57-43
20794
P- 12

ABSTRACT

The concept of integrating ecological perspectives on early man's settlement patterns with advanced remote sensing technologies shows promise for predictive site modeling. Early work with aerial imagery and ecosystem analysis is discussed with respect to the development of a major project in Maya archaeology supported by NASA and the National Geographic Society with technical support from the Mississippi State Remote Sensing Center. A preliminary site reconnaissance model will be developed for testing during the 1991 field season.

INTRODUCTION

Early man was much more closely attuned to his immediate environment and to the attributes of the ecosystems in which he lived and through which he traversed than we of modern society. He, therefore, probably based his site selection process on the ease with which he could obtain food, water, and shelter from a given ecosystem, and the terrain attributes which would enable him to assume a defensive posture when required. Escape routes probably also played a role in the decision-making process (Miller et al. 1974). Although perhaps swayed more by access to trade/transportation routes than the aborigines, the early European settlers during the early 1830's were still attuned to the relative advantages of different ecosystems (Miller 1981). Unfortunately, man learned to control his environment too efficiently, too soon, and consequently found it easier to modify an ecosystem/environment than to learn to live within the inherent constraints of that site. Dr. L. R. Holdridge (1966) set forth some extremely cogent archaeological concepts when he introduced his Life Zone Ecology classification. He points out that the earliest agricultural development was in regions with a "unity line of potential evapotranspiration"--regions where the annual precipitation equals the annual evapotranspiration (ETp). The significance of this line is that soil nutrients are recycled through some saturation and percolation downward, but movement upward to the surface occurs when the soils become dry through the ETp process. According to Holdridge, if the capital cities of 22 American republics are plotted on his Life Zone chart, 19 will fall in a Life Zone adjacent to the unity line. The exceptions are Lima, Peru; Panama City; and Santiago, Chile. In the case of Lima, only a Subtropical Desert Life Zone location was available for a seaport. It is interesting to note that the ancient Incan capital had been located at Cuzco in a life zone next to the unity line. In Chile, the Araucarian Indians succeeded in keeping the Spanish from moving further south and thus Santiago is located one Life Zone removed from preferable.

The earlier site modeling studies cited for Mississippi utilized aerial color infrared (CIR) imagery

* Director, Mississippi Remote Sensing Center.

** Principal Scientist/Archaeologist, NASA/ John C. Stennis Space Center

*** Geoinformation System Specialist, Lockheed Engineering and Sciences Company

in conjunction with a study of the spatial terrain and ecological attributes of known sites of the correct vintage. From this cross-tabulation, a working site model hypothesis was developed. This model incorporated the cultural attributes presumed to drive settlement patterns (Miller et al. 1974). During the flight to acquire imagery of the known sites, a second area within which archaeologists knew that there were a number of sites was also flown. The model was tested and an 80% recovery rate was found; i.e., 80% of the sites identified as highly probable were, in fact, sites. This means that we only tested "sins of commission," and not omission. A similar model was obtained by modifying some of the ecological/terrain concepts to conform to early European settlement patterns. Two extinct towns were located, and a high degree of success was also achieved in discriminating "cultural activity sites" circa 1834-1856 (Miller 1979, 1981).

In addition to predictive modelling, remotely sensed data have been used to directly locate archaeological features in both arid and tropical environments. In the desert of Chaco Canyon, New Mexico, airborne data were used to locate and map prehistoric Anasazi roads. Many of these roads were not visible either from ground level or in simultaneously acquired aerial photography (Sever 1990). Airborne imagery was also used in the tropical forest of northern Costa Rica to locate a network of prehistoric footpaths near the Arenal volcano (Sheets and Sever 1988).

As a result of this early research, and in line with NASA's Office of Commercial Programs initiative, a joint project was developed between NASA's Science and Technology Laboratory at the Stennis Space Center (NASA/SSC), the National Geographic Society (NGS), the Mississippi Remote Sensing Center (MRSC), and a private sector organization, Geoinformation Services, Inc. (GSI). In order to secure funding, a commercialization project required cooperation between a lead NASA Center (SSC), an end-user of space technology (NGS), a university remote sensing laboratory (MRSC), and a private sector entity (GSI) to serve in a technology transfer role between the end-user and the technical centers. Because of the National Geographic's interest in the Maya culture (Vol. 169:4, Vol. 172:3, Vol. 176:4), the project naturally became oriented to development of a reconnaissance model for Classic/Pre-Classic Maya cities. The decision was not difficult since between personnel at NASA/SSC, MRSC, and GSI, there was sufficient expertise to develop and test a model.

PROCEDURES

A. Field Work. The first phase of the field work was accomplished during March of 1989 with a team consisting of personnel from the Guatemalan Comision Nacional del Medio Ambiente (CONAMA), GSI, NASA, and Lockheed. A number of sites in the Department of Peten of northern Guatemala were visited. The major purpose of this short trip was primarily to assess logistical problems associated with access and transportation to remote sites. A number of fairly accessible sites were visited in an attempt to gain insights into spatial organization of the cities and surrounding environmental/terrain features: Dos Lagunas, Rio Azul, Uaxactun, and Tikal were targeted for this first year. To some extent, the development of a site selection hypothesis depends upon observation of known sites, a study of known cultural attributes, and intuition.

The field team was re-assembled in February 1990, and now includes Dr. James Nations, the Vice President (Latin America) of Conservation International. Dr. Nations had also participated in the field work during the first season, but in a different capacity. This season was devoted to a further observation of ecological/spatial relationships of major remote city sites, and acquiring the cartographic location of each by means of a hand-held Global Positioning System receiver. This inexpensive system was

estimated to provide latitude and longitude within approximately 30 meters or less and altitudes within 5-7 meters.

B. Use of Remote Sensing Technologies. With these locational data, Yaxchilan, Piedras Negras, Seibal, Tintal, Tikal, and Mirador will be input to a geographic information system (GIS) digitized from 1:50,000 quadrangle maps. The aircraft and satellite remotely-sensed data collected during the spring of 1990 will be classified and input to the GIS. The aircraft data will include radar, Thermal Infrared Multispectral Scanner (TIMS) data, a calibrated airborne multispectral scanner (CAMS), and color infrared imagery. The TIMS and CAMS data were collected at five meter resolution. In addition, two dates of Thematic Mapper data from Landsat 5 will be used both for current land cover and as a means of detection of encroachment across the Guatemalan border into the Peten. The latter analysis will be performed to assist CONAMA. The boundaries of the recently legislated Biosphere Reserve areas (Garrett 1989) will also serve as a data layer in the GIS.

C. Data Analysis. The procedure used to establish a reconnaissance model after development of a preliminary settlement hypothesis is simply to cross-tabulate city locations with site attributes such as proximity to a potable water supply (aguadas or bajos), spatial relationships with surrounding agricultural areas and outlying satellite villages, presumed transportation routes, and distances from adjacent major sites. Vegetation patterns will also play a role in the model, but the extent or significance is not yet known. It is anticipated that a preliminary model will be available for testing during the 1991 field season. The land cover data will be utilized to provide inventory data and information to assist with the management of the Biosphere Reserves (Figure 1).

This project is also analyzing remotely sensed data in order to directly detect features in the imagery which may be associated with prehistoric activity. For instance, satellite data, airborne data, and CIR photography have been used to map the location of cenotes in the Piedras Negras area which could have been used prehistorically as sources of potable water (Figure 2). Cenotes have been indicators of Maya sites in other areas such as Chichen Itza (Kurjack 1987) in the northern Yucatan. The Maya also used cisterns to collect rainwater for their water supply, but the dependability of cisterns is limited by the amount of rainfall during the long dry season. Future fieldwork will determine if the cenotes in the Piedras Negras region are associated with Maya sites.

Computer filtering techniques and fractal analysis have also been conducted to accentuate linear and curvilinear features in both the TIMS and CAMS data. These features, such as Maya sacbes (causeway), are occasionally visible in the CIR photography (Figure 3). Computer techniques have previously been employed to locate prehistoric features such as roads, paths, agricultural fields, causeways, and walls at Chaco Canyon, New Mexico; Poverty Point, Louisiana; and Arenal, Costa Rica (Sever 1990). Analytical techniques using radar data have also been used to locate ancient Maya agricultural fields in Belize (Adams, Brown, and Culbert 1981). Future ground reconnaissance in the Peten area will determine whether or not the features isolated in the TIMS and CAMS data are expressions of prehistoric human activity.

DISCUSSION OF WORK TO-DATE

At this point, based primarily on field observation, it would appear that at least two model hypotheses must be developed: a riverine model and an interior model. The interior cities seemed to be reliant on the presence of extensive agricultural areas and proximity to potable water supplies. The

trip from Carmelita to Tintal and Tintal to Mirador was quite interesting, and the travel revealed a repetitious landscape pattern which can best be described as, beginning with a “bajo,” low terraces and extensive “benches” separated by an occasional low limestone ridge which was occupied by mounds and grave sites. From this low ridge, the benches, terraces, and bajo sequence was repeated (Figure 4). A bajo is now a seasonally-flooded, low-lying area (Figure 5). It is fairly obvious that the benches were intensively farmed, and the outlying satellite villages occupied the low limestone ridges with the major city site occupying the highest ridge or limestone outcrop in the region. This pattern was picked up as we approached Tintal from the south and continued on the north side all the way to Mirador--there must be some point of division between the two cities, but it was not apparent. The concept of a city surrounded by “. . . enormous gardens with bands of trees used to mark boundaries” (Adams 1986) would seem unlikely given the nature of the soils of the Peten. The senior

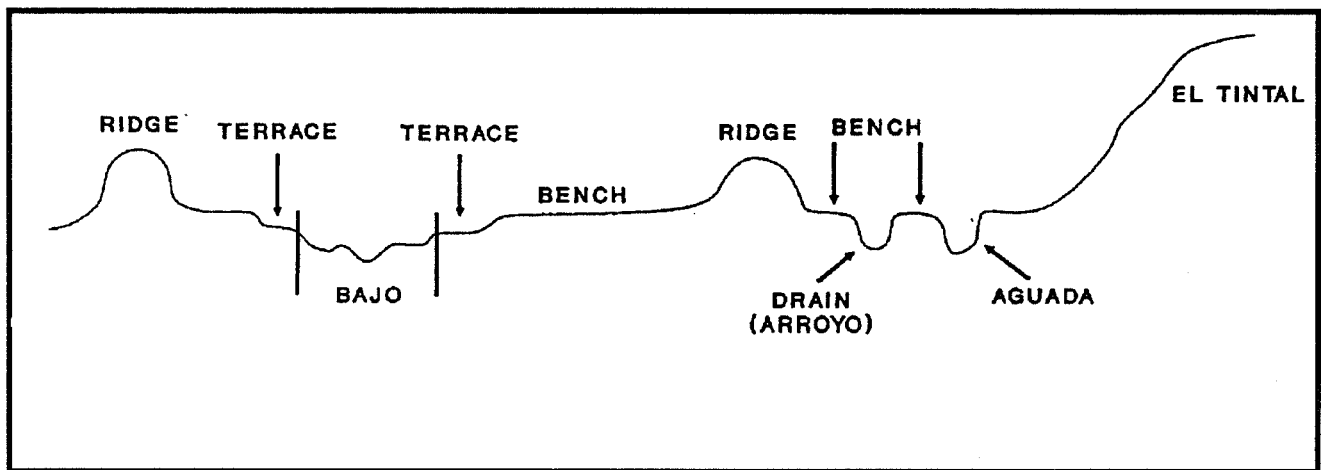
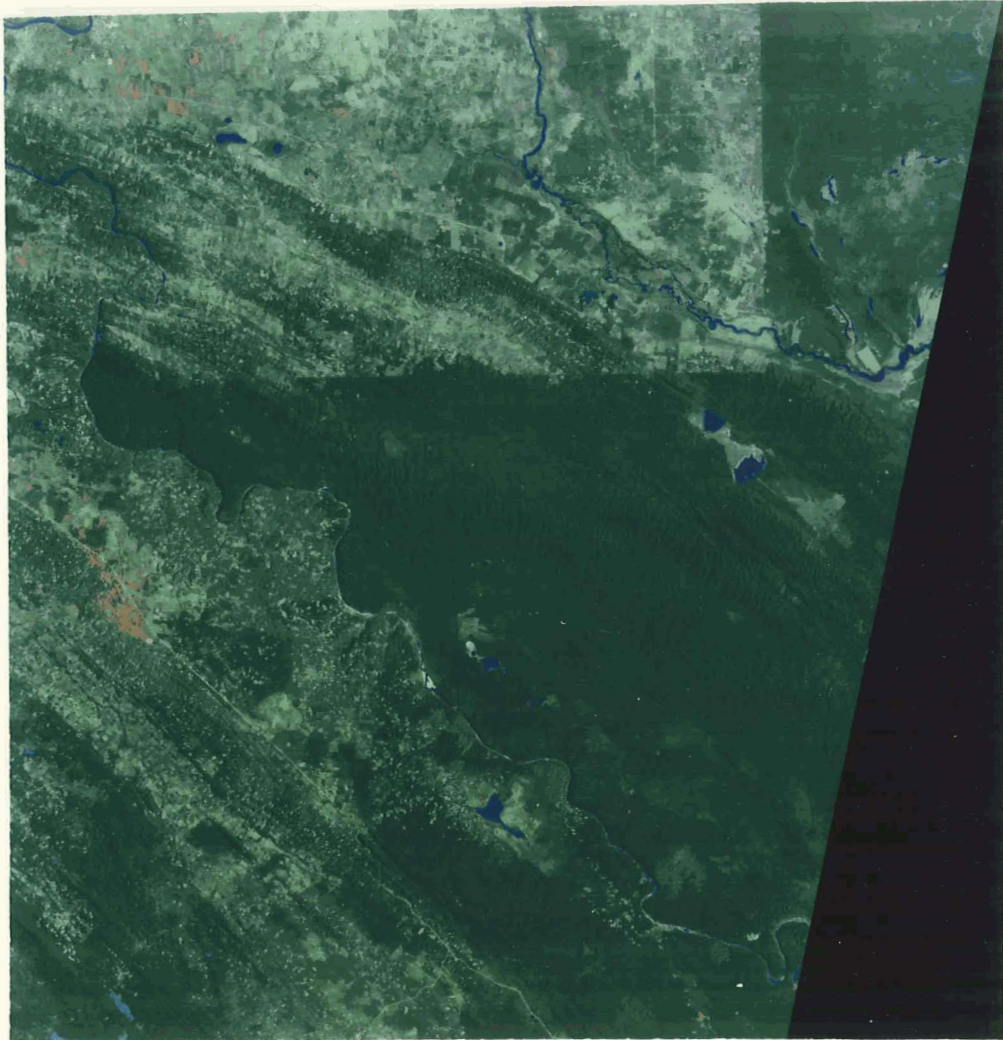


Figure 4. Landscape relationships of Maya sites.

author's field notes indicate that the terraces slope from 1% to 4% toward the bajos, and given the nature of the Vertisols the probability of severe sheet erosion is high. Even though the Peten lies in a Life Zone close to the unity line, this still cannot account for long-term intensive cultivation without addition of soil amendments by the Maya or, more likely, the practice of some form of milpa agriculture (Nye and Greenland 1965, Watters 1971). These soils tend to have a high shrink/swell potential, and with the onset of the rainy season, tend to seal the cracks and pores rapidly, thus preventing the entire profile from becoming saturated. The question then arises as to whether the bajos were originally sink depressions (karst topography) with fresh water lakes which filled with the products of erosion from the benches and hillsides over the centuries (see Summary).

Both interior and riverine sites placed a strong preference on selecting sites with a commanding defensible position. The interior sites were generally the hub of the transportation routes, and as such controlled ingress and egress to their sphere of influence. The riverine cities were also located in strong defensible sites which overlooked and controlled trade routes from the interior to the river, and traffic on the river. They also appear to be more reliant on trade, with a somewhat lesser emphasis on agriculture. The valleys leading from the river to the interior in the vicinity of Yaxchilan and Piedras Negras, in addition to serving as trade routes, probably also were the major agricultural production areas. These sites are still preferred by the indigenous population for the practice of milpa, or shifting agriculture.

ORIGINAL PAGE
COLOR PHOTOGRAPH



USUMACINTA RIVER VALLEY

TM DATA MAY 20 1988

Figure 1. TM classification showing the political border between Mexico and Guatemala. This image reveals the impact of high rural population upon the rain forest. The dark green area represents Guatemala's sparsely populated Peten district as it stands in contrast to the stripped and tilled landscape of Mexico.

ORIGINAL PAGE
COLOR PHOTOGRAPH

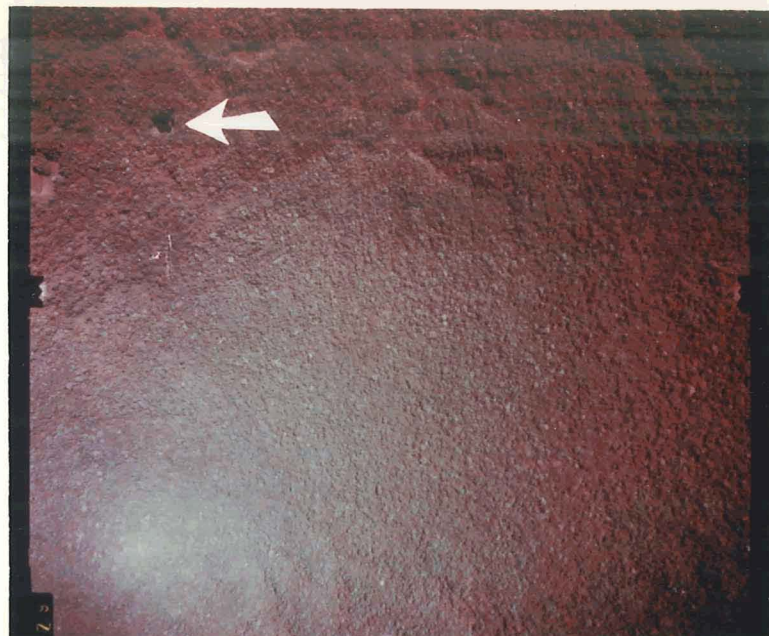


Figure 2. Top: CIR photograph showing an arrow pointing to a cenote within the vast forest canopy of the Peten. Cenotes may have been used as sources of potable water for the Maya in this region near Piedras Negras.

Bottom: Close-up of two cenotes in the Sierra de Lacandon region near Piedras Negras.

ORIGINAL PAGE
COLOR PHOTOGRAPH

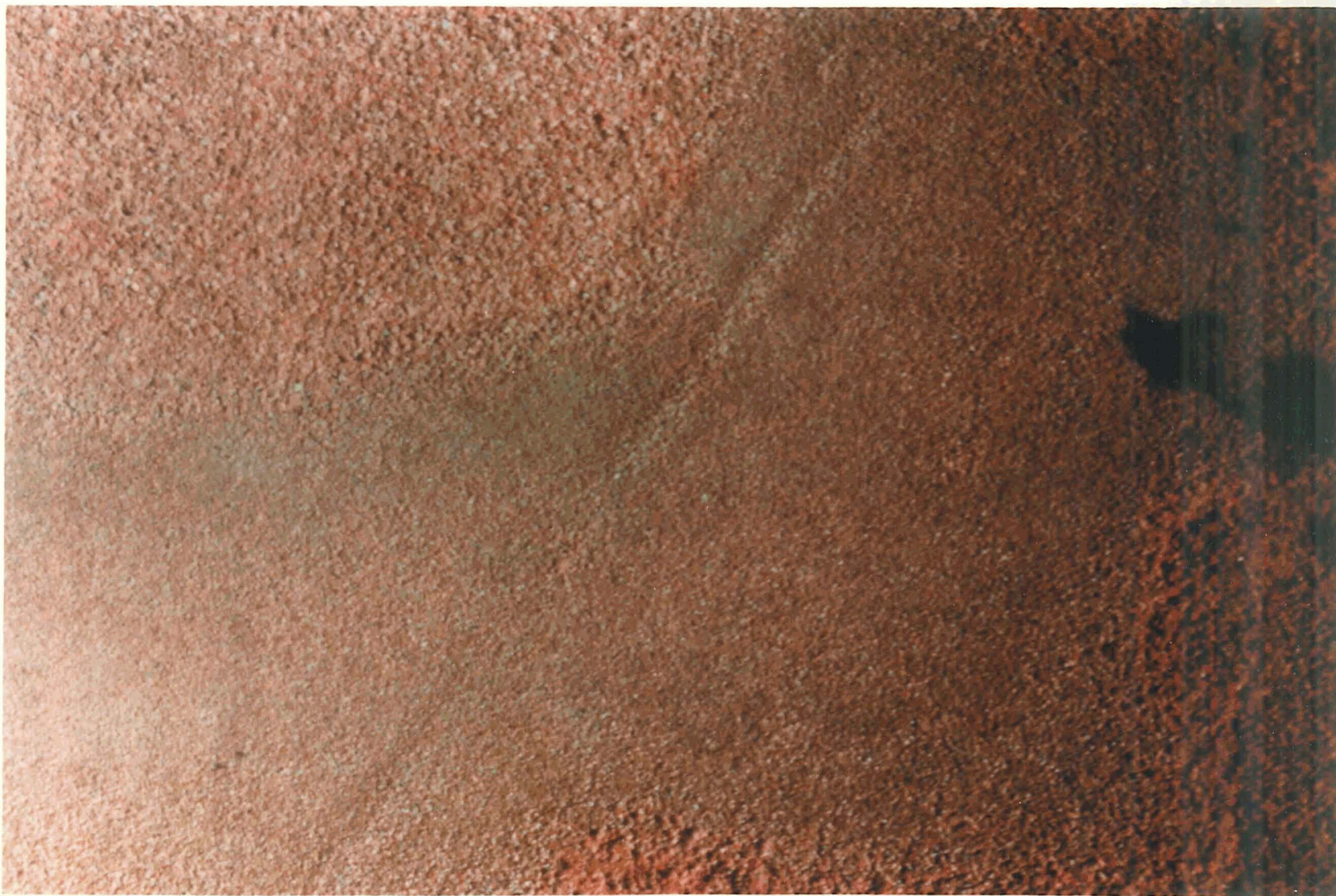


Figure 3. CIR photograph showing a linear feature which is a Maya causeway entering the archeological site of El Mirador in the northern Peten.

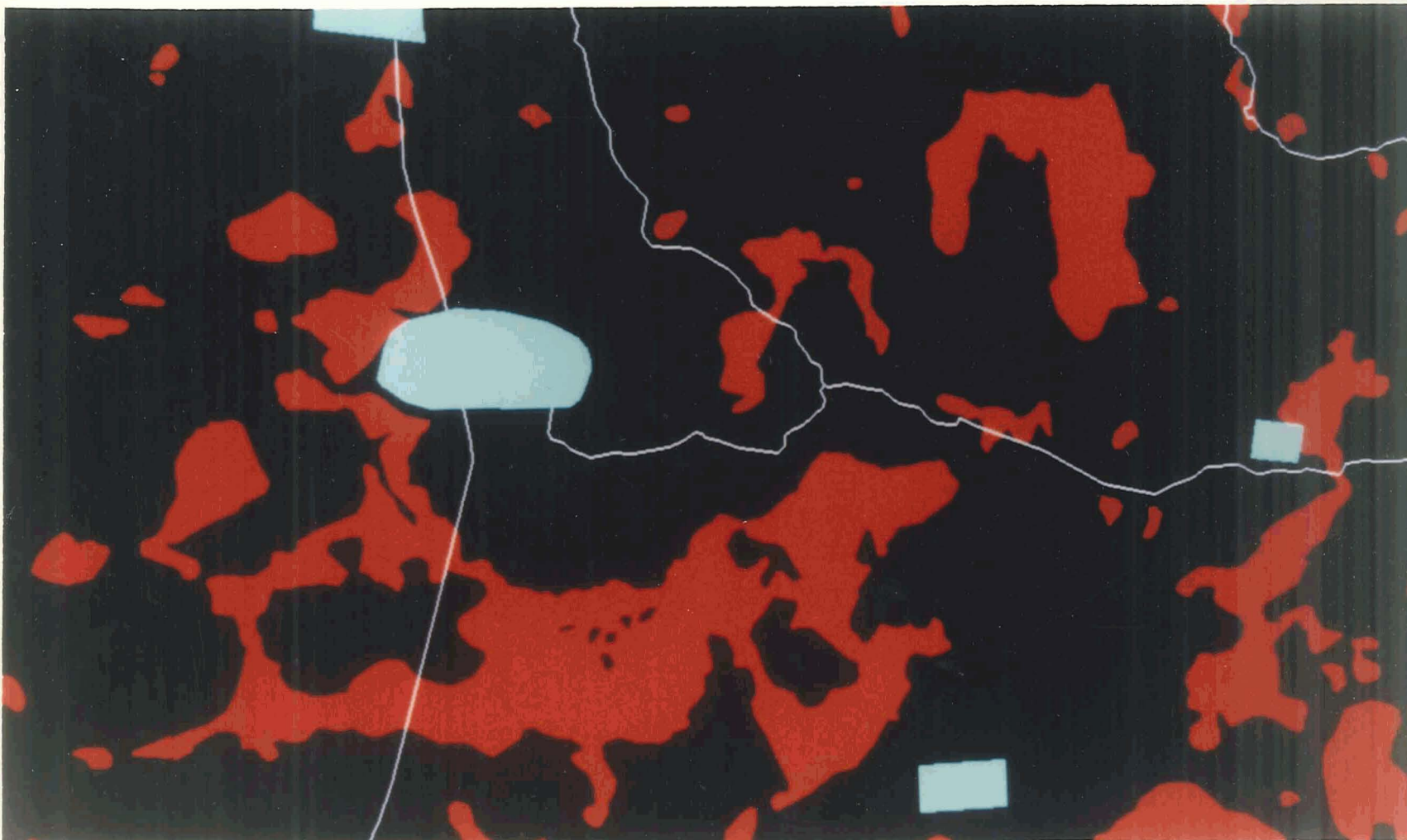


Figure 5. Data output from the Peten GIS. The data were digitized from the Mirador quadrangle sheet at a scale of 1:50,000 with a 20 meter contour interval. The red polygons represent "low forest" which are indicative of "bajos" (seasonally flooded, freshwater swamps). Archeological sites are represented in blue with contemporary trails shown in white.

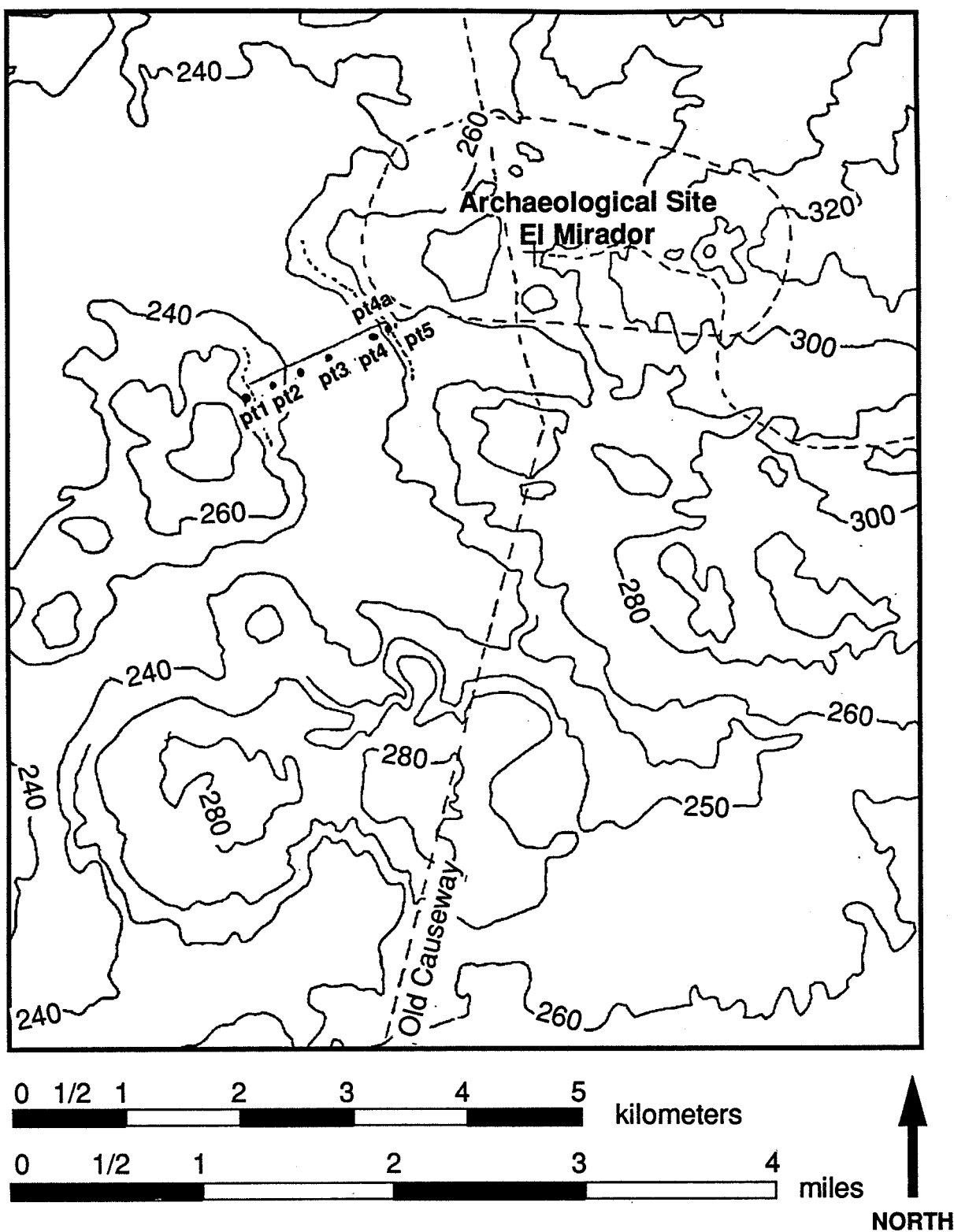


Figure 6. Sampling transect on bajo - SW of Mirador camp.

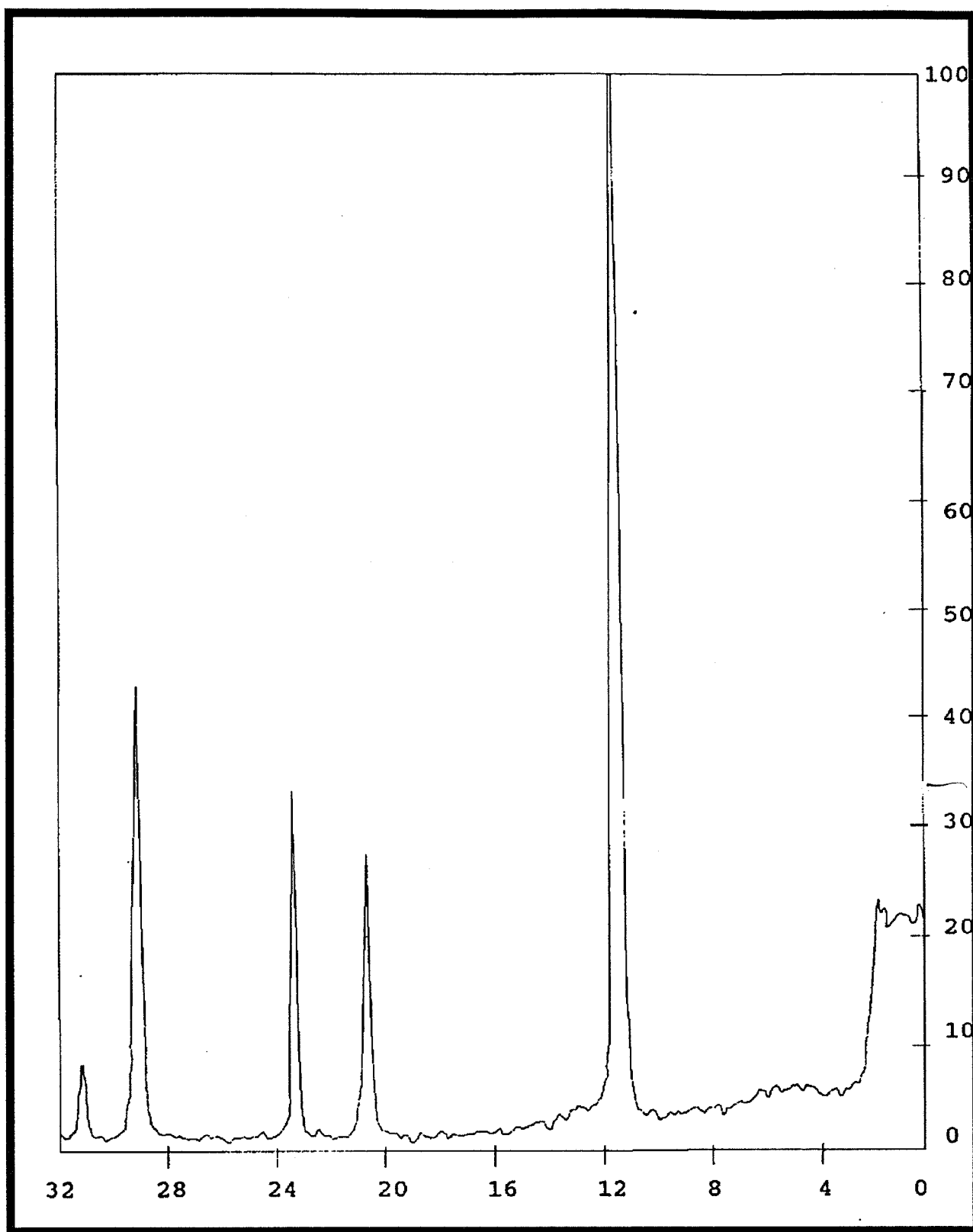


Figure 7. X-Ray Diffraction of crystal found at 170cm - Pit 4.

SUMMARY

Based on two field seasons, preliminary analysis of one date of TM data, and a small amount of color infrared imagery, guidelines for the first run at the development of a settlement model have been formulated. The first approximation should be completed in time for the 1991 field season, and will be tested in the field, or, depending upon the extent of guerilla activity, from low-level aircraft. In addition, cenotes and other features in the CAMS and TIMS data which may be associated with pre-historic activity have been mapped. These features will also be tested during the field season.

The hypothesis that the bajos were fresh water lakes during the Classic period has been at least partially substantiated by analysis of soil/sediment samples from five, 3-meter-deep pits on a transect across the Mirador bajo to the southwest of the city (Figure 6). Sample analysis is incomplete at this point, but what has been tested greatly resembles a highly gleyed profile consisting of 1.0 to 1.5 meters of colluvium/alluvium from the terraces, benches, and sidehills resting unconformably on at least 2 m of evaporites with large gypsum crystals as indicated by X-ray diffraction (Figure 7).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation and assistance they received from the Guatemalan Comision Nacional del Medio Ambiente (CONAMA), specifically from Sr. Jorge Cabrera, Coordinador, and Santiago Billy, Encargado Patrimonia Natural; and Dr. James Nations, now Vice President (Latin America) of Conservation International, who, with Santiago, arranged the in-country logistics that made the trips possible. Both men were convivial companions on all the field trips, and made life much more enjoyable by their presence. The monetary and moral support given this project by the National Geographic Magazine must also be mentioned, specifically the enthusiasm and support given by Jon Schneeberger and Bill Garrett.

REFERENCES

- Adams, Richard E. W. 1986. Rio Azul: Lost City of the Maya. *National Geographic* 169:420-451.
- Adams, Richard E. W., W. E. Brown, Jr., and T. P. Culbert 1981. Radar, Mapping, Archeology, and Ancient Maya Land Use. *Science*, Vol. 213, No. 4515.
- Garrett, Wilbur E. 1989. La Ruta Maya. *National Geographic* 176:424-479.
- Holdridge, L. R. 1967. Life Zone Ecology. Tropical Science Center, San Jose, Costa Rica, C.A.
- Kurjack, Edward. 1987. Personal communication.
- Matheny, Ray T. 1987. El Mirador: An Early Maya Metropolis Uncovered. *National Geographic* 172:317-339.
- Miller, W. Frank, M. D. Walls, and Crawford Blakeman. 1974. Applications of remote sensing in

archaeological site identification. Center for Environmental Studies, Miss. State Univ., Miss. State, MS 39762.

Miller, W. Frank. 1979. Remote sensing applications in archaeological investigations: Sharpley's Bottom, Vinton, Barton, and Colbert, Miss. A final report to Interagency Archaeological Services, Atlanta, GA.

Miller, W. Frank. 1981. Remote sensing techniques in historical site discrimination. *Remote Sensing of Environment* 11:463-471.

Nye, P. H., and D. J. Greenland. 1965. The Soil Under Shifting Cultivation. Tech. Comm. #51, Commonwealth Bureau of Soils, Farnham Royal, Bucks, England.

Sever, Thomas L. 1990. Remote Sensing Applications in Archeological Research: Tracing Prehistoric Human Impact Upon the Environment. Doctoral dissertation, University of Colorado. University Microfilms, Ann Arbor, Michigan.

Watters, R. F. 1971. Shifting Cultivation in Latin America. FAO of the UN, Rome, Italy.

NEW TECHNOLOGY AND REGIONAL STUDIES IN HUMAN ECOLOGY: A PAPUA NEW GUINEA EXAMPLE

George E.B. Morren, Jr.

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

58-45
201795
P. 28

ABSTRACT

Two key issues in using technologies such as digital image processing and geographic information systems are (1) a conceptually and methodologically valid research design, and (2) the exploitation of varied sources of data. With this realized, the new technologies offer anthropologists the opportunity to test hypotheses about spatial and temporal variations in the features of interest within a regionally coherent mosaic of social groups and landscapes. Current research on the Mountain OK of Papua New Guinea is described with reference to these issues.

INTRODUCTION

This paper reports work in progress on a multi-year project that is using remote sensing and related technologies to study social and environmental change in the Mountain Ok region of Papua New Guinea. A key strategy is the compilation of a regional digital environmental and ethnographic atlas via the medium of a geographic information system (GIS). Forest disturbance and disturbance-related human activity are currently the principal foci of the study which has gained adequate funding only recently.

The Mountain Ok region of the island of New Guinea embraces the headwaters and upper reaches of three major river systems, the Fly, Strickland, and Sepik Rivers in the high country in the center of the island. This area is a north-south biogeographical break and a major ethnographic demarcation in the highlands of New Guinea. The distribution of peoples and cultures in the New Guinea Highlands is (according to my reckoning) organized by eleven high intermontane valley systems: from east to west, the first eight (Airona-Aiura, Goroka, Wahgi, Lai, Ialibu-Pangia, Mendi-Nipa-Lai, Lagaip and Tari-Koroba) are the centers for the 'classic' New Guinea Highlands cultures such as the Simbu and Enga; the ninth valley system, Ifitaman-Oksapmin-Sibil is the center of the Mountain Ok culture area; with the Baliem (the center of the Dani area) and Paniai Lakes in Irian Jaya/West Papua the tenth and eleventh.

In the wet mountains, population seems to cluster in these valleys because (1) they are broad and mountain rimmed resulting in clear sunny days and, hence, ideal agricultural conditions, and (2) good agricultural land in gentle lower slopeland and even bottom land if it can be drained. Elsewhere in the mountains crop success is reduced by excessive cloud and moisture (hence reduced light) and rough topography with good agricultural land more spottily distributed. The best examples of these densely settled valley systems are Wahgi-Lai of the Enga and Baliem of the Dani, both with crude densities in excess of 100 per km². In contrast, the valleys of the Ifitaman system range between ca. 7 and 11 per km² making it the smallest of the eleven in terms of population. This status is probably also associated with another distinction; in most of the Ifitaman and associated valleys, Colocasia taro is the staple, whereas sweet potato dominates subsistence in the other ten valley systems.

*Department of Human Ecology, Cook College, Rutgers, The State of New Jersey

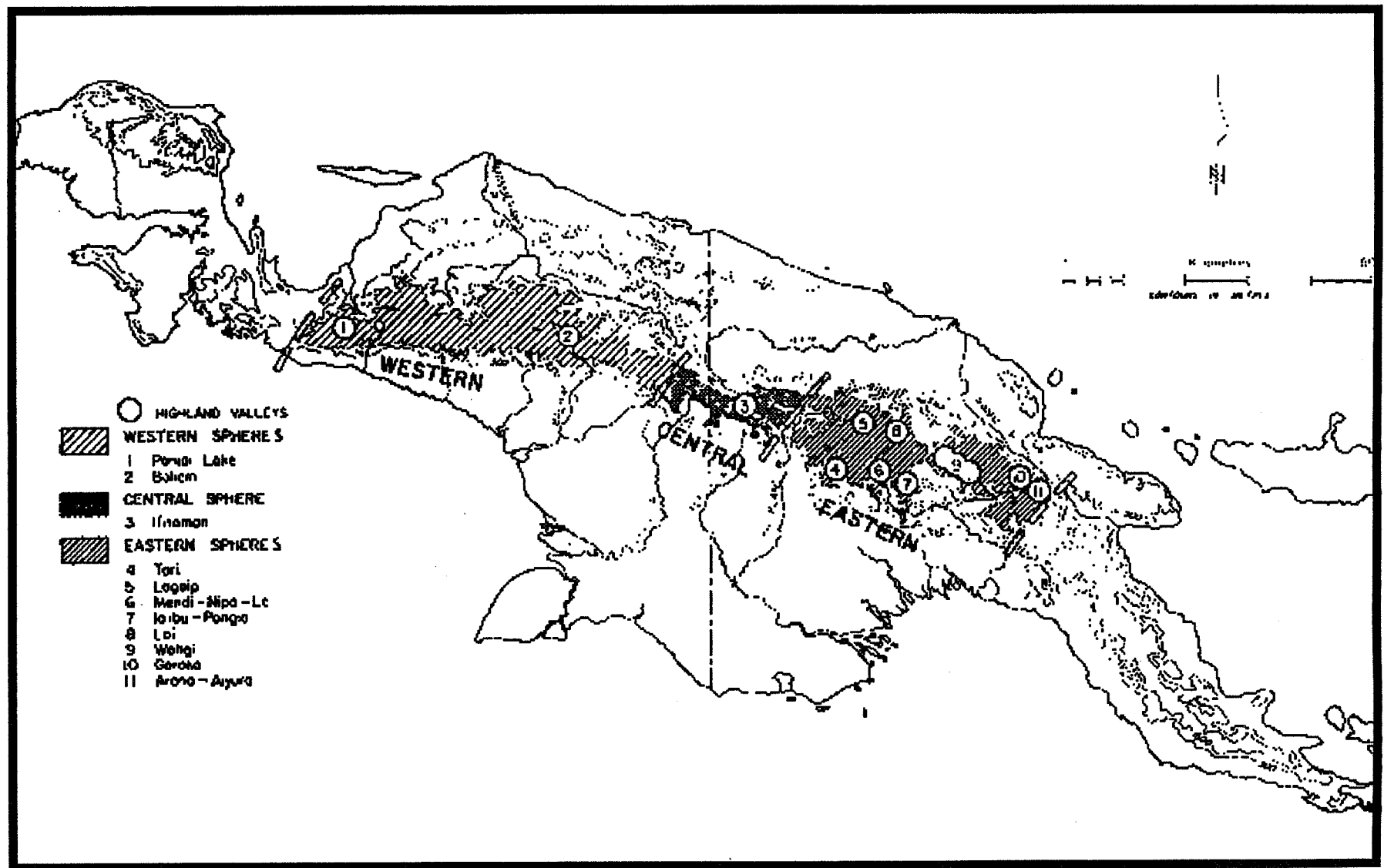


Figure 1. Highland Spheres of New Guinea (from Hyndman & Morren, 1990).

My general concern is the impacts of indigenous peoples on tropical moist forests under both traditional and modern conditions. There are pragmatic as well as theoretical reasons for this concern. The pragmatics of using remote sensing in anthropology is that we need phenomena that can be detected. Forest disturbance, other environmental changes, and more obvious artifacts such as settlements fill the bill. Moreover, the phenomena in question should have theoretical importance, so that an underlying assumption is that environmental changes can tell us much about sociocultural change and variation locally and regionally.

More or less independently, anthropologists and ecologists have begun to take notice of the dynamic character of both New Guinea societies and vegetation. If, as ecologists have argued, tropical forest richness is due to tree falls (see Brokaw, 1985 for a review), then what has been the impact of thousands of years of human tree felling activities? And to what extent and with respect to what features may tropical forests be regarded as artifactual?

Two keys to using such new technologies as remote sensing, digital image processing, global positioning systems (GPS), and geographic information systems (GIS) that I highlight in this paper are (1) a conceptually sound and methodologically valid research design, and (2) the exploitation of the varied sources of data that may be available. With this realized, the new technologies offer ecological anthropologists an unusual opportunity to move from a conventional community focus to achieve the original objectives of controlled comparison in which hypotheses about spatial and temporal variations in the features of interest can be tested within a regionally coherent mosaic of social groups and landscapes. Agricultural variability, settlement pattern, environmental disturbance, circulation, migration, and modernization are among the features that appear to be particularly susceptible to comparative and longitudinal investigation using these technologies. I describe current research on the Mountain Ok area of Papua New Guinea with particular reference to conceptual and methodological issues, diverse data sources, and relevant analytical techniques.

The overall project has eight principal objectives:

- * acquire and analyze multitemporal remotely sensed data, first on a sample transect, and then on the Mountain Ok region as a whole;
- * assemble a geographic information system (GIS) data base or 'digital atlas' for the study area to include geocorrected and georeferenced classifications of satellite data, aerial photographs, and digitized topographic, geological, vegetation, settlement, agricultural, demographic, and sociocultural data (broadly defined);
- * depict the course of forest disturbance under a range of environmental conditions and low to moderately intense human activity regimes;
- * test replicable procedures for studying human activity and forest change at both local and regional scales;
- * conduct ground verification and related social research in the field;
- * explain past and current patterns of forest disturbance;
- * test the relationship between cultural variability and spatial and environmental factors including

disturbances; and

* demonstrate appropriate technical and field procedures and substantive results to relevant institutions and agencies in Papua New Guinea.

REMOTE SENSING IN ANTHROPOLOGY AND RELATED FIELDS

For most of this century, remote sensing in the form of aerial photography has been employed by archaeologists, cultural anthropologists, geographers, planners, ecologists and researchers in related fields for mapping, land use and agrarian studies, forest cover and resource assessments, settlement pattern investigations, and the like (Collier, 1967; Ebert, 1988; Ebert et al., 1983; Heller, et al., 1983; Vogt, 1974). Although the analog photographic medium provided the means to gather otherwise inaccessible data and extend the geographical scope of research (Hackenberg, 1967), the depth and analytical power of such studies was limited by the need to hand process the data. Conklin's studies of traditional agriculture in the Philippines (1974, 1980), the work of Bourne (1928), Cochrane-Patrick (1931), and Robbins (1934) on African agricultural and resource development, Heinsdijk's (1952) and Swellengrebel's (1959) forest survey work in Surinam and Guyana, and Pajman's (1966, 1970a & b) forest studies in Papua New Guinea are landmarks of this kind (see also Schorr, 1974; Boon, 1956, and Johnson, 1969 for reviews).

The launching of LANDSAT satellites and the development of digital image processing and data management technologies have revolutionized these applications, making more data available at lower cost, expanding the scale at which studies can be conducted, permitting accurate location determination, and increasing by several orders of magnitude the amount of information that can be extracted from the data. Relevant studies include work on swidden agriculture (Reining, 1973; Conant & Carey, 1977, Conant, 1978; Carey, 1985) and people forest interactions in Africa (Wilkie, 1988, Wilkie and Finn, 1988), tropical deforestation in South America (Tucker et al., 1985; Nelson et al. 1986; Woodwell et al., 1986, 1987), and Borneo forest fires (Malingreau et al., 1985). Today, general limitations reside in the fact that some of the phenomena of interest to anthropologists and landscape ecologists, such as stands and disturbances, tree-falls, settlements, and agricultural fields, may be at the margins of resolution of satellite imagery. This has been a particular problem with the MSS system of LANDSAT 1 to 3, introduced in 1972, which has an optimal digital resolution of 57 by 80 m. The TM system of LANDSAT 4 and 5, and the SPOT systems, both dating from 1986, have improved this considerably with resolutions of 30 by 30m for TM and 20 by 20m (multispectral) or 10 by 10m (panchromatic) for SPOT. In addition, mathematical and other techniques permit considerable data and image enhancement so that it is technically feasible to classify phenomena or ground events of less than pixel size, especially when digital data are augmented by ground verification and other kinds of collateral data sources such as aerial photographs and topographic information. Problems also pertain to work in particular zones and world areas such as cloud contamination in tropical moist forest areas such as Papua New Guinea, high relief as in my study area, the absence of a long time series of controlled aerial photos, and so on. I am optimistic that some of these, such as the small area phenomena problem and the time series issue can be mitigated and I will discuss some examples.

As discussed subsequently, the use of geographic information system (GIS) software such as the GIS module in the Earth Resources Data Analysis (ERDAS) software package or the Geographic Resource Analysis Support System (GRASS) not only facilitates this augmentation greatly, but

allows us to manage and integrate large amounts of information in ways never possible before. This integration of satellite remote sensing, image processing, and GIS technology is considered to be the last major breakthrough because diverse kinds or layers of spatially registered data, including multitemporal data and sociocultural information, can be interwoven "seamlessly" (Ehlers et al, 1989).

CONCEPTUAL ISSUES

Although this technology is promising, many remote sensing studies of real-world situations in ecology, resource management, agriculture, land use, and on cognate anthropological topics are conceptually weak, descriptive, focused narrowly on technical improvements, or embodying misleading preconceptions. Hence, the need to discuss conceptual issues. The subsequent discussion focuses on two central issues; the development of a non-equilibrium view of human and biotic communities in landscapes and the rationale for a regional study.

My project focuses on five levels; the cultural region (or what is designated subsequently as the 'sphere'), the ethnolinguistic group, the landscape, the biotic community level and human residential groups within landscapes, and individual people. The regional level concerns ever-changing large scale patterns and distributions among components in time and space and, according to the conceptualization presented subsequently, asks particular questions about the movement of people, the relations between core and fringe groups and their landscapes, and the nature of boundaries between regions or spheres. The biotic community level, which is the pivot of this research project, is concerned with how species interact, the characteristics of the species interacting, and how those interactions are influenced by the non-living environment. The quotidian activities of humans is a 'species characteristic' of particular concern. Accordingly, from a community perspective the guiding question in this research is, what is the role of indigenous people in organizing tropical moist forest communities in Papua New Guinea? Or, what features of tropical moist forest communities are consequences of people's movements and actions? Related to the foregoing is the question, how can we explain people's movements and actions and, hence, also the consequences of those actions? And, if some typical features of tropical moist forests are artifactual, how long do they persist?

A Non-equilibrium View of Societies and Ecosystems

Beginning in the last decade, cultural anthropologists and ecologists undertook parallel conceptual shifts away from equilibrium-based conceptualizations of social system and ecosystem function respectively (Colinvaux, 1973; Vayda & McCay, 1975, 1977; Morren, 1986). Until the 1970s, anthropologists commonly studied indigenous societies as if they were unchanging, tranquil, and timeless (at least until disrupted by; e.g., Western contact). Therefore, under the paradigmatic name of functionalism (Radcliff-Brown, 1952), the focus of analysis was on the maintenance of some kind of social equilibrium or, later, on a balance with the environment (e.g., Rappaport, 1969; Morren, 1974). Subsequently, this paradigm was to give way to critiques (Bates & Lees, 1979; Dory, 1961; Moore, 1975; Ortner, 1984; Rutz, 1977), concerns about individual behavioral variability, complexity, and disequilibrating events such as environmental hazards and war (Vayda, 1976; Morren, 1984), and the adoption of individualist approaches that bring people back in as rational actors in situations (McCay, 1981; Vayda, 1986). This has led to recognition that even before Western contact, indigenous societies, including those of Melanesia, were characterized by flux, change, and often considerable turbulence (Schrire, 1984; Watson, 1983).

Ecologists have traversed similar ground. Equilibrium-based concepts such as ecosystem and succession denoted the dominant paradigm in the field into the 1970s when they came under increasing criticism (Engleberg & Boyarsky, 1979; Drury & Nesbitt, 1973; Horn, 1976; Simberloff, 1980). Since then, under the rubric of patch dynamics and landscape ecology, some ecologists have attended to disturbances as disequilibrating events, recognized the non-climax character of ecosystems, and emphasized the study of species interactions within dynamic patchy landscapes (Pickett, 1980, 1983). Some of these questions about 'climax theory' first emerged in the context of tropical forest studies in the 1930s (Aubreville, 1938). As described subsequently, vegetation researchers in New Guinea have begun to adopt this view as well.

The conceptual scheme guiding this research brings together these developments in seemingly disparate fields. It combines the landscape ecology/patch dynamics approach in ecology (Forman & Godron, 1981; Pickett, 1980, 1983) with methodological individualism in the social sciences (Dray, 1980; Vayda, 1986). Accordingly, it views the forest and the people dwelling in it as a mosaic of ever-varying human groups and landscapes. At the methodological level, the objects of explanation are human actions and their consequences (Vayda, 1986). The distribution, frequency, predictability, and severity of certain measurable environmental disturbances (Foster, 1980) are intended or unintended consequences of individual movements and actions. Disturbances can be assessed in terms of their causes (e.g., anthropogenic vs. 'natural'), spatial and temporal distribution, plant community composition and structure, successional dynamics, and vegetation heterogeneity (Runkle, 1985). Human actions are explained by reference to people's intentions and the contexts in which actions occur (Vayda 1983). Thus, the objective is to discover why people cut down trees or engage in other forest disturbing activities, and why they shift the locations in which they engage in them. Explanations here will focus on peoples intentions; e.g., the extent to which disturbance-related consequences are intentional or not, and the wider contexts in which people make and implement decisions; e.g., activity of other groups, resource scarcity, perceived opportunity, modernization pressure.

A Rationale for Regional Studies in Ecological Anthropology

The phrase controlled comparison recalls Fred Eggan's (1954) attempt to encourage comparative studies that were both spatially oriented in focusing on 'cultural regions' and temporally oriented in being concerned about process and change rather than the distribution of traits. Such comparisons are 'controlled' because they involve a smaller scale than 'world' ethnographic samples, utilize regions embracing groups that are historically and/or culturally related, and permit closer attention to ecological features.

Many researchers in New Guinea have called attention to spatially defined uniformity and integration within the great diversity that characterizes the cultures of New Guinea, labeled variously "cultural regionalism" (Bulmer, 1982:175), "regional cultures" (Chowning, 1982:166), or "areal cultures" (Schwartz, 1962). A regional and inter-regional perspective on change and variation in highland New Guinea is anchored in a more realistic appreciation of the relationship between groups of the regional core (or center) and fringe. Conventionally, the term 'fringe' has been applied to "the interior mountain people surrounding the Highlands" (Brown 1978:28). And the relationship of fringe peoples to the highlands has been characterized as a "population sink" (Stanhope 1979); that is, due to stable low populations possibly controlled by malaria, people drift down slope from denser high altitude groups to the fringe. Conceptualizations such as these may obscure important variations within and between regions.

Elsewhere, Hyndman and I (1990) have adopted the term sphere to distinguish regional units. In our usage, "a sphere is a potentially expansive, segmentary, reticulated mosaic of local groups that share a common tradition and are strongly influenced by one or more core populations at the historic geographic center(s) of their region." Spheres have frontiers rather than boundaries. Frontiers describe the zones in which spheres meet and compete or, through their occupation, reduce uncontested margins. Contiguous groups within a sphere are linked or separated (as the case may be) by marriage, mobility, migration, exchange, alliance, ideological differences and similarities, cooperative demonstrations, competition or conflict. Changes at the center, particularly demographic ones, ramify to the fringes, while changes at the fringe, particularly involving resource accessibility and trade, reach ultimately to centers. For the most part, we used published ethnographic and environmental data in an attempt to describe the dynamics of the Mountain Ok sphere (Hyndman & Morren, 1990). For example, there is evidence of both downslope and upslope movement of migrants in the Mountain Ok and elsewhere in montane New Guinea (e.g., Lowman, 1980; Watson 1983, 1985; Morren, 1986).

Following Brookfield and Hart (1971:77), the New Guinea Highlands is characterized by a very large number of small communities in their distinctive landscapes, all local, open, interconnected in various ways and aggregated into larger more inclusive units which are also open. At least within territorially defined regions, all local communities are interconnected, although the influence of any one on any other will diminish or slow as a function of distance, the number of intervening groups, and/or the location of frontiers. Accordingly, fringe groups might be better defined as "people in between" the centers of different spheres. Thus as I have argued elsewhere (Morren 1984, Hyndman & Morren 1990), in order to comprehend the dynamics of the highlands, it is necessary to examine how a region relates to the lowlands as mediated by the groups of the mid-altitude fringe or how fringe groups associated with one sphere interact with those of others.

Knauff's (1987) recent article on intragroup homicide among the Gebusi of Papua New Guinea nicely illustrates the issue of intergroup variation in the context of regional population distribution and movement. The Gebusi are lowland representatives of the Strickland Plain-Papuan Plateau-Mount Bosavi sphere which is also represented by, for example, the higher altitude Etoro (Kelly 1977, Dwyer 1982). Knauff describes a larger regional pattern in which several "sociocultural features" change incrementally with altitude from group to group otherwise sharing a cultural tradition. Directly related to altitude are reliance on root crops and hunting, population density, health status, material exchanges, importance of collective intergroup violence (warfare), intragroup social control (reduced intragroup violence), and leadership based on eldership and experience in warfare. Such environmental-population-behavioral gradients are probably observable all over New Guinea and certainly exist in the Mountain Ok sphere (Morren, 1987, 1986:159-162, 194, 237-239, 281; see also Gardner 1981; Hyndman & Morren, 1990), and provide a rationale for isolating a sample transect for intensive study as described subsequently.

PEOPLE IN LANDSCAPES

This study will examine initially a 20km X 60km transect that combines gradients associated with altitude and biogeographical zonation (Johns, 1972; Hyndman, 1982), human population density, and modernization. The southern end is anchored in Telefomin, a high valley (at ca. 1600m ASL) that is a regional population center as well as the modern administrative and commercial center. Moving north, the transect crosses forested ranges of up to 3000m ASL and terminates in the lowlands of the

middle May River at ca. 80m ASL. Declining human population density, greater mobility and dispersion, and reduced modernization impacts are also associated with this south-north transect. Subsequently, the GIS data base and overall investigation will expand in scope to take in the Mountain Ok region as a whole. There is also a future prospect of extending it westward to embrace such groups in Irian Jaya as the Mek and the Dani.

Centered on the source basin of the Sepik River which consists of a cluster of partially deforested high intermontane valleys, the Mountain Ok region straddles the central cordillera of the island of New Guinea and extends into the northern and southern lowlands (Figure 2). Forest types include lower montane beech forest above ca. 1400m, lower montane coniferous forest above ca. 2400m, and lowland hill forest below 1400m (Johns, 1972, 1977). Extensive grasslands are dominant features of the intermontane valleys. Over much of the region, current and former swiddens and settlement sites produce fairly distinctive stands and patches.

A series of landscapes are present in the study area (Figure 3). According to Forman and Gordon (1981:733), a landscape "is a kilometers-wide [i.e., large!] area where a cluster of interacting stands or ecosystems is repeated in similar form. The landscape is formed by two mechanisms operating together within its boundary -- specific geomorphological processes and specific disturbances of the component stands." For this study I employ the natural boundaries delineating major catchments to

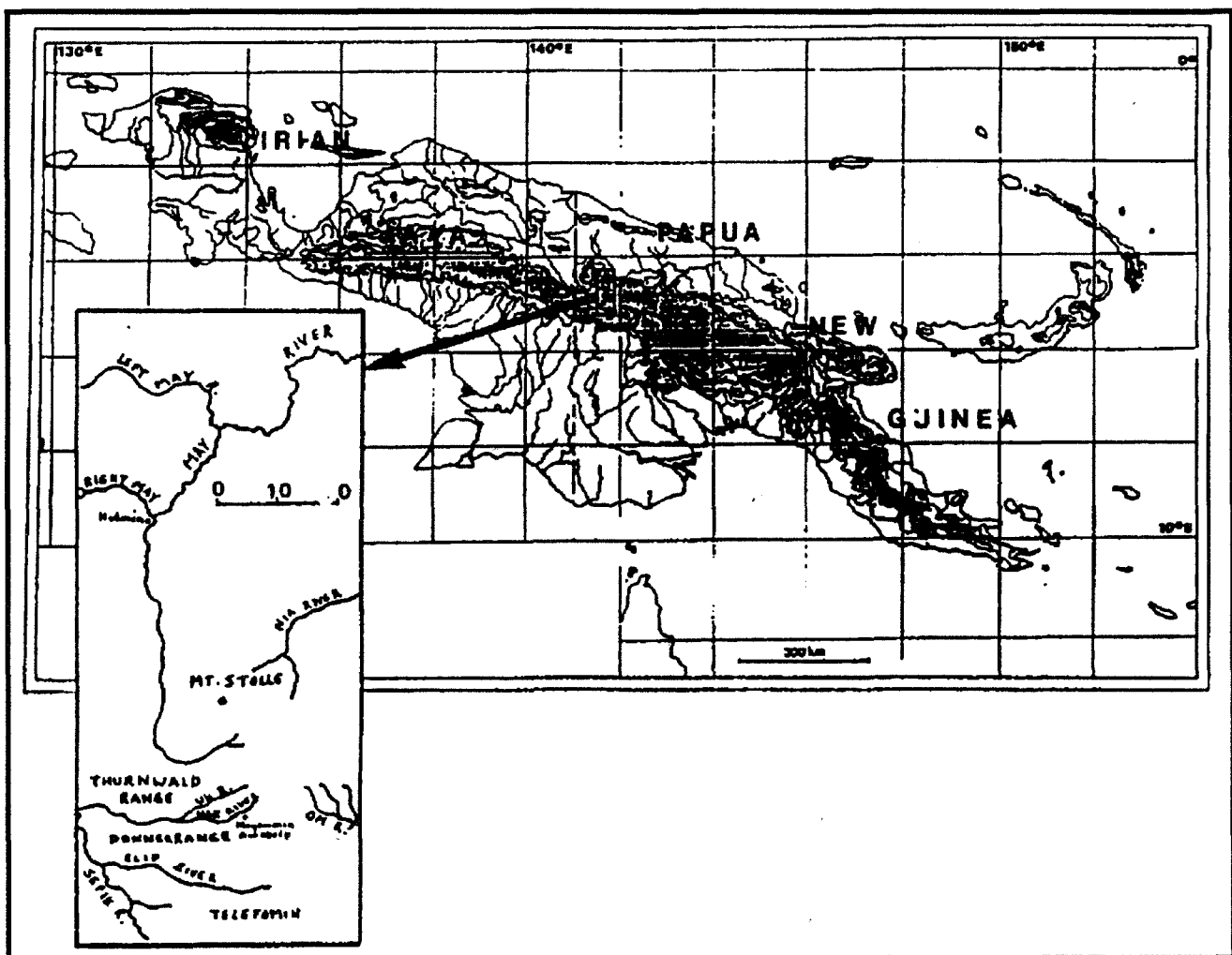


Figure 2. The study area and location in Papua New Guinea. (from Morren, 1990; courtesy of Science in New Guinea)

ORIGINAL PAGE
COLOR PHOTOGRAPH

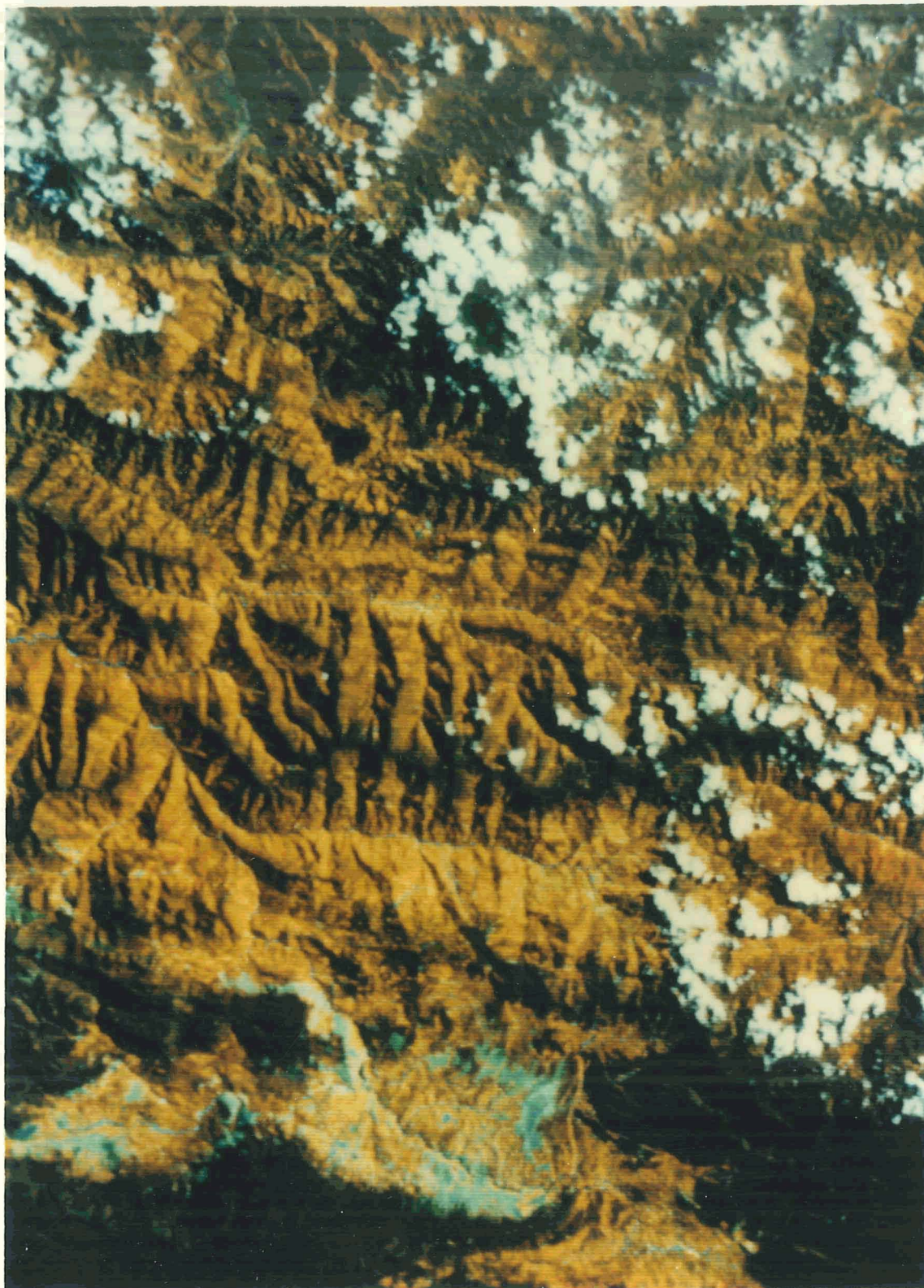


Figure 3. Subscene of Landsat IV, Path 100, Row 63, 10/22/86, Bands 4,5,3.

define landscapes. On this basis, when viewed downslope from south to north, the transect I am studying currently includes three fairly distinct landscape types of particular interest:

- (1) the intermontane valley of Ifitaman and connected valleys consisting of a gulleyed alluvial fan surrounded by mountains. There are extensive grasslands on the valley floor and lower slopes, and relict montane forest stands and second growth in the gulleys where agriculture is practiced. This landscape is repeated in other adjacent valleys such as Oksapmin.
- (2) steep river valleys in the Donner and Thurnwald ranges such as those of the Elip and Hak rivers and certain upper May River tributaries. These consist of montane and lower montane forest, and varying amounts of secondary and old growth forest.
- (3) the flood plane of the middle May River and adjacent areas not subject to inundation. This is characterized by lowlands rainforest and sago swamp strongly influenced by seasonal flooding as well as cusps of foothills with stands of lower montane vegetation and widely dispersed stands of secondary and old growth forest.

There are valid methodological, empirical and operational reasons for including this much landscape variation and diversity in the research design. The methodological reason is that the notion of landscape provides a useful framework for undertaking a regional analysis. The empirical reason is that some indigenous people are conversant with and move among these landscapes or biotopes (Hyndman, 1982), modifying their behavior in relation to such features as the kind and distribution of resources and hazards and benefiting from regional trade. The operational rationale is to test the capability of remote sensing, digital processing, geographic information systems, and related technologies to identify and measure disturbances and other small area events and phenomena in a variety of contexts and manage a large, complex data base.

People, their actions and the consequences of those actions have been integral to these forests for 20,000 years (Hope, 1983; Swadling, 1983). Long established human activities (Sillitoe, 1983; Clark, 1971; Steensberg, 1980) include the use of fire to create grasslands, shifting agriculture (slash-burn and slash-mulch) (Morren & Hyndman, 1990), building new settlements constantly (Morren, 1980, 1986), hunting forest fauna (Morren, 1977, 1986, 1988), pig husbandry (Morren, 1977) and exploiting minor forest products such as timber, tree leaves, and rattan.

In the modern context, there are also some minor local forestry operations and road and walking track construction. National and local modernization pressures have reduced mobility, increased settlement size, and induced extensive forest clearing activities such as airstrip construction and small-scale commercial agriculture (Morren, 1981). These traditional and modern activities vary among groups and landscapes.

The nature of grasslands that were particularly notable in the Markham Valley and also prominent in other high montane valleys was an issue that emerged early in the study of cultural evolution in the New Guinea highlands (Robbins, 1958). Researchers of that time concluded that these grasslands were anthropogenic and a link to population growth was proposed (Watson, 1965). More geological, climatological, and archaeological knowledge has changed the way we view these grasslands so that we now understand that their origins, maintenance, or expansion involves a complex of factors. While they predominate in valley bottoms in some places, grassland succession forced, then followed, cultivation up the slopes in other places (Bowers, 1970), and augmented the adoption of sweet potato

in subsistence production. Yet in other places, perhaps even Telefomin, expansion cannot be clearly linked to agriculture. Nevertheless, Robbins' original observation was a vehicle to develop a tentative understanding of people as agents of biotic change in New Guinea and interest has focused particularly upon agriculture. We now understand that human activity leads to a variety of disturbance regimes including, but not limited to, agricultural impacts, that these have influenced landscapes and biotic communities throughout New Guinea, and that irreversible disturbance or degradation has had significant social implications (Allen & Crittenden, 1987).

The dynamism and non-climax nature of New Guinea forests has become increasingly evident to vegetation researchers there (e.g., White, 1975; Johns, 1986; Frodin, 1987), even as anthropologists have come to recognize parallel characteristics in the societies of the island. The proposition that the two dynamisms -- landscape and 'peoplescape' -- are intertwined, is central to this research.

There are perhaps two configurations of social instability in the human dominated landscape. The first, which appears pertinent to the Eastern Highlands, the mid-altitude fringe universally, and much of the Mountain Ok region, involves high group mobility, individual circulation, fluid settlement patterns, and group flux, and is part of what was until recently a sustainable pattern of agriculture and resource use (Morren & Hyndman, 1988). Only a few anthropologists and geographers working in New Guinea have examined group and individual mobility in any depth (e.g., Watson, 1983, 1985; Lowman, 1980; Morren, 1986), while others remark on it in passing. Limiting himself to the Eastern and Western Highlands, Feil (1987:49) finds that nucleation and fluidity decline from east to west. This is in accord with Brown and Podolefsky's (1976:215) findings. Feil (1987:50) relates dispersed homesteads to expanded swine production. Rappaport (1968:69) and Waddell (1972:87) have described cyclical patterns of nucleation and dispersal driven by growth of the local pig herd. For the Miyanmin, further west, I have described a similar cycle driven by declines in game, and agricultural and other resources as well as social factors (Morren, 1980; 1986:245-47)

The second configuration of instability, that seems to be most apparent in the Western Highlands groups that participate in extensive exchange networks, involves an unsustainable cycle of growth following a group's pioneering a new or recovered area, and decline after a powerful group achieves a high degree of success in attracting personnel, allies, regional prestige and hegemony, and prosperity. This can also be characterized as a vicious cycle of population increase and demand for food and other resources, intensive and expanding swine production with its demand for fodder, ever expanding agricultural production which modifies the landscape heavily, the pressure of exchange and warfare (and perhaps modern commercial and political competition), and demographic success (Watson, 1977; Morren, 1977). Paradoxically, success leads to degraded resources and sometimes irreversible landscape modifications, rising competition, the threat of failure and defeat, and community dispersal and destruction (Meggitt, 1977; Lowman, 1980). Other events, such as natural disasters, contact, and modernization can intervene with similar consequences (Waddell, 1975).

Varied Data

The data base necessary to elucidate the issues discussed so far is large and varied in nature and, hence, complex and difficult to acquire, manage, and analyze.

The study area, including the sample transect and the Mountain Ok region, has not been the subject of a regular, systematic survey and mapping program comparable to that of an industrial country or of modern commercial and political rivals. Yet it has been subjected to intermittent, drawn

out, even episodic contact and observation, and some uncontrolled aerial and landscape photographs exist from at least the 1913 because most visitors did photography and, beginning in the 1930s, most were supported by aircraft. Old photographs are useful at a minimum for dating events that may leave persistent marks that can be examined currently. Accordingly, I would certainly encourage readers to think about the possibilities in your own research areas if there is any conceivable payoff. In my case, I have begun to find what I was looking for. It has also produced an interesting spinoff project to build an account of early contact and its impacts for different groups in the region using the valuable ethnographic photos and even some film I've found that had not previously seen the light of day. This in turn provides the needed data to document the landscape and aerial photographs.

The key to finding this material is to focus first on the individuals who produced it (or might have produced it), tracing their lives, subsequent activities, even family survivors. You write a lot of letters -- sociologists call it 'snow ball sampling' I think -- trying to tap into networks, past and present, the existence of which you may only hypothesize. I have also found that the worst place to look -- bar none -- is in official U.S. government repositories; they are either hopelessly chaotic or else surrounded by coils of red tape. For example, although I have spoken to the man who, as a U.S. Airman, took aerial reconnaissance photographs of the Ifitaman valley prior to the 1944 glider landing there, I have not yet found these WWII photos of the area.

I started my search for really early aerial and landscape photos late in 1988. My hope was, and continues to be at a minimum to date certain events such as settlements and forest disturbances in individual photos and, at best, to assemble sets of photos to permit the construction of mosaics for local areas for a given time frame.

Hence, since the turn of the century when the area was part of the German Empire, the perceived need to assess and develop resources has motivated basic exploration limited mainly by capital and the technology of transportation and data gathering. The first Westerners to penetrate the area and thus define the edge of prehistory were members of the German Kaiserin-Augusta Flus [Sepik River] Expedition of 1912-14 who carried out an extensive mapping survey program of areas accessible by boat or short mountain ascents. The expedition, which included the anthropologist Richard Thurnwald, the first Westerner to reach Telefomin in 1914, took photographs, and gathered basic geological, botanical, ethnographic and other scientific information. Until the late 1970s, their map was the most accurate of the upper Sepik region. I am currently on the track of expedition data, have recently found four of Thurnwald's Telefomin photographs, and also located some of his sketch maps of the area.

Subsequent visitors to the area included an official exploratory patrol in 1928, a gold prospecting party in 1936-37, an administrative patrol of 1938, and a U.S. glider landing in 1944. Three of these operations were supported by aircraft and all four generated some useful landscape and/or aerial photographs which have been or will be acquired. The first comprehensive controlled aerial photography of the area was produced between 1968 and 1973. A map overlay of flight tracks and selected scenes from this source have been acquired. In addition, I shot two series of uncontrolled oblique color aerial photographs of portions of the transect area in 1968 and 1989 and have 20 years of village-level population and settlement data for portions of it.

Useful LANDSAT data for the study area is difficult to obtain because of cloud contamination. Of the hundreds of scenes of the transect area gathered by ground stations between the initiation of the LANDSAT program in 1972 and 1989 (when I last reviewed microfiche records in Canberra, Australia), only three have been acceptable. (LANDSAT 4 and 5 data for New Guinea including micro-

fiche records, are only accessible in Australia.) No useful SPOT images have been produced so far. In addition, topographic, geological and vegetation maps of the transect area have been obtained. Airborne radar data collected in connection with minerals exploration in the region are being pursued currently.

To date, a working remote sensing data set has been assembled for the study area: 1972 and 1988 LANDSAT digital data, 1968 and 1989 uncontrolled oblique color aerial photo mosaics, selected 1973 controlled aerial photographs, uncontrolled aerial and landscape scenes from 1936 and 1944, environmental maps, and village census data. The search for and acquisition of additional analog, digital, and ancillary data to permit a true regional study continues.

GIS Data Base

A digital 'environmental and ethnographic atlas' constituting a multilayered GIS system that incorporates processed and georeferenced remote sensing data and other kinds of environmental and cultural information is being constructed of the diverse data listed previously for the study area using established procedures (Ehlers et al, 1989; Iverson et al, 1988; Kramme, 1986; Strahler et al, 1978; Tomlinson, 1984). This will be augmented with official census data and village-level population data I collected beginning in the 1960s, settlement histories, and site-specific information extracted from field notes and ethnographic sources. Ground truth and other field information will be added when available. As indicated previously, the GIS data base will assist in enhancing satellite data with ancillary data (Hutchinson, 1982, Paijmans 1966, 1970; Miller, 1960; Hopkins, et al, 1981). Possible "layers" or data planes of this GIS data base are presented for illustration only in Table I.

The incorporation of sociocultural data into GIS systems has been only preliminarily discussed in the literature. Accordingly, this dimension of my project is frankly exploratory. What follows is a preliminary attempt to "think through" the problem of incorporating sociocultural data (broadly defined) into a geographical information system (GIS) that otherwise consists of mapped physical information including remotely sensed data from satellites and other sources. A researcher may have a variety of objectives in mind when incorporating sociocultural data into a GIS. These include:

- * spatial prediction and modeling,
- * controlled cultural comparison, and
- * explanation at the individual and aggregate or holistic level.

The main advantage of the GIS for these purposes is the ability to incorporate, manage, and use immense amounts of data from diverse sources.

The principal criterion for using a GIS is that the data be mappable (spatially registered). That said, there seem to be at least four possible (though not mutually exclusive) approaches to mapping sociocultural information of the kind that has long been of interest to sociocultural anthropologists: (1) trait-based, following established crosscultural coding schemes such as those represented by the *Ethnographic Atlas* (Murdock, 1967); and the *World Cultures* journal (White, 1985-86), or variants developed for particular purposes; (2) survey-based, involving data derived from repetitive surveys of local communities or sites in a region; (3) artifact-based, following the lead of archaeologists (who

TABLE I. Possible Data Planes of a projected GIS System

1. a base map of ground control points;
2. enhanced and georeferenced 1972 LANDSAT MSS data;
3. enhanced and georeferenced 1988 LANDSAT TM data;
4. spectral classifications of the LANDSAT data;
5. digitized elevation map;
6. digitized slope map;
7. digitized aspect map;
8. digitized geological map;
9. digitized vegetation map;
10. digitized 1968-73 controlled aerial photos;
11. settlement map for a sample periods (more than one are likely);
12. village level population data;
13. ground truthing plots
14. botanical plot survey data after ground verification;
15. plot land use history data;
16. digitized 1968 uncontrolled oblique aerial photographs;
17. digitized 1989 uncontrolled oblique aerial photographs;
18. digitized and corrected 1936 aerial and landscape photo data;
19. roads and tracks;
20. streams;
21. drainage;
22. digitized 1914 Behrman map of Mai and upper Sepik penetration;
23. Carius & Champion (1928) route and camps;
24. Williams party (1936-37) route and camps;
25. Hagen-Sepik (Taylor-Black) Patrol (1938) route and camps;
26. Thurston party (1941) route and camps;
27. n. other collateral data.

have made more extensive use of GIS than other anthropologists); and, (4) event-based, recording specific human activities and other events in spatial and temporal terms.

1. A trait-based approach may suffer from some of the same methodological difficulties that have assailed established cross-cultural survey techniques. It tends toward a static view of human behavior, enforcing the illusion of cultural stability that arises in part from the exigencies of ethnographic reporting. This limitation might be superceded partially with serial ethnographic reports and restudies. Then it would be feasible to assign data to separate planes in the GIS as well as registering it in spatial terms since field sites are sometimes varied within the nominal sociocultural cell, territory or unit. Still, there would be a tendency toward spatial 'crudity', the attribution of a cultural trait to a very large sized cell. Hence the search for associations through the data planes would be ambiguous. In connection with this phase of the project, it would certainly be fiesible to code, according to a scheme yet to be developed, the now extensive literature on Mountain Ok peoples (see Hays, 1990, for an up-to-date bibliography), but I am not yet convinced of its usefulness, not at least in relation to current objectives.

2. A survey-based approach incorporates survey data that has been collected in a series of communities in a region. Obvious examples are village-level or tract-level census material, sociolinguistic or

ethnoscience survey data, agricultural production and food consumption data, health, nutrition and growth data, and the like. Some of this kind of data is available for the sample transect area in the form of census material collected by Morren in 1968-69 and 1981 and in official census and health records. The latter material may also be available for the region as a whole.

3. An artifact-based approach follows the practice of archaeologists who have long experience in managing an excess of spatially and temporally defined data. Hence, archaeologists have made more extensive use of GIS than other anthropologists (see Kramme and Kohler, 1988 for a review) in studies aimed at organizing and displaying data and predictive modeling. Artifacts are simply mapped in one or more data planes in relation to a base map and other data planes of collateral environmental data so that distributions and other dimensions may be compared across data planes. (As always) key questions here are, 'What is an artifact?' and 'Which artifacts are important?' This mode is particularly pertinent to this project's study of vegetation stands, settlements, agriculture, resource areas, and other disturbance sites, all possibly qualifying as artifacts.

(4) Because it deviates from established ways, the 'event-based' approach is discussed in greater detail. Simply stated, an event is something that happens at a particular time and place. Thus, an event-based approach maps specific human actions and other events including associated mechanisms, personnel, consequences, intentions and physical and social contexts in spatial and temporal terms. The methodological advantage of an event-based approach is that it allows us to look at the behavior of individuals rather than accepting the holistic assumptions built into the other approaches, particularly numbers 1 and 3. It also involves small cell size, permitting much greater specificity in the search for coincidents and associations. Its main disadvantage is that it requires data of a sort that rarely emerges from the ethnographers notebook in retrievable form. Like number 3, it requires a precise, worked out research design. It may also be feasible to disseminate one or more survey instruments to researchers who have worked in the Mountain Ok in the past, a procedure used previously by Morren and Hyndman (1988; Hyndman & Morren, 1990). Table II provides a preliminary list of events.

My pilot use of the 'event-based' approach focuses on the drawn out, localized, and highly episodic contact and modernization history of the region which, as indicated above, commenced in 1912. Data on expedition routes and camps as well as documented contacts and associated social and environmental impacts will be entered in the GIS. The rationale is that a regional study needs to get a good fix on the transition from prehistory in particular locales if one is concerned with quantitative and qualitative differences between pre- and post-contact patterns of change.

By visual inspection I have already established that it is possible to detect and measure features

Table 11. Sample Lists of Events

Human Activities	Contextual Events
tree felling	flood
building	drought
collecting	frost
coming	blite
staying	epidemic
going	early contact
hunting	attack
birthing	commercial penetration
dying	landslide
homocide	earthquake
'contacting'	vulcanism
'ritualing'	
'big speeching'	
planting	
weeding	
harvesting	
feasting	

of interest from LANDSAT 4 and 5 data, such as settlements, swiddens and swidden-related second growth stands. The primary means of achieving this is through a process called classification in which the computer is instructed to identify significant spectral clusters (Jensen, 1978, 1979, 1986) (see Figure 4). This needs to be followed up with some kind of verification of classes either through ground truthing or surrogate means. With good classes established, a change analysis can be accomplished in which the computer compares successive scenes representing different time periods (Banner et al., 1981; Malita, 1980) (Figure 5). A GIS system facilitates this kind of analysis greatly. I am still struggling with difficulties affecting classification associated with high relief and sun angle.

With data organized around spatial coordinates in a GIS it is then possible to study coincidence, measure areas and distances, and apply weighted logic, boolean operations, and regression analysis through the "layers" of data to at least tentatively test hypotheses and explore research questions such as the following even without field verification:

What is the relationship between disturbance and distance from regional centers?

What is the relationship between disturbance and settlement pattern?

What is the relationship between disturbance and local concentrations of population?

What is the relationship between disturbance and ethnicity? For example, all else equal, do Telefomin communities create disturbances that can be distinguished spectrally from those created by Miyanmin communities?

What is the relationship between disturbance and altitude?

What is the relationship between disturbance and agricultural regimes?

Is there a relationship between anthropogenic disturbance regimes and vegetational patterning?

Do the frontiers separating spheres have distinctive spectral characteristics (reflecting vegetation characteristics due to absence of disturbance)? And might this speak to the relationship between the Mountain Ok and the Mek peoples and of the latter to the Yali/Dani or of the Mountain Ok, particularly the Miyanmin and the Abou to the north?

Do modern bush airstrips produce disturbance patterns comparable to those produced by roads?

Some Preliminary Results

I have extracted worthwhile though preliminary results from a classification map for a single time period. I produced several alternative classifications of my sample area last spring (I returned from the field in August to find that two of our remote sensing labs hard drive units has crashed and had not been backed up and this classification work was lost). With one of them I was able to extract some preliminary findings on the relationship between forest clearing and different kinds of settlements:

- * Within 5km of small villages 1 - 2 % of land is cultivated or disturbed.
- * Within 5km of large villages 3 - 4 % of the land is cultivated or disturbed.
- * Within 5km of large villages with airstrips 4 - 12% of land is cultivated or disturbed.

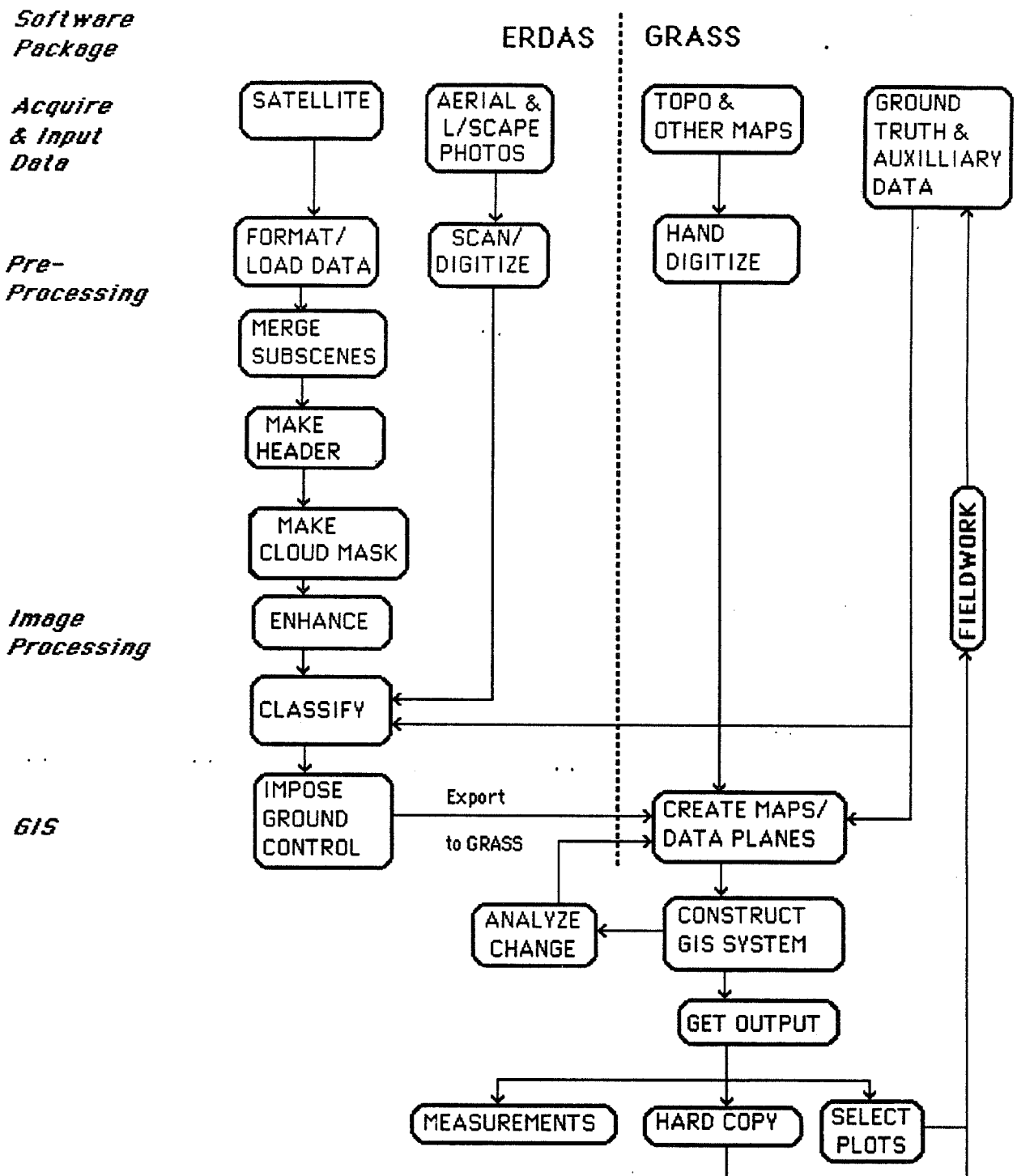


Figure 4. Building a digital ethnographic atlas of the Mountain OK.

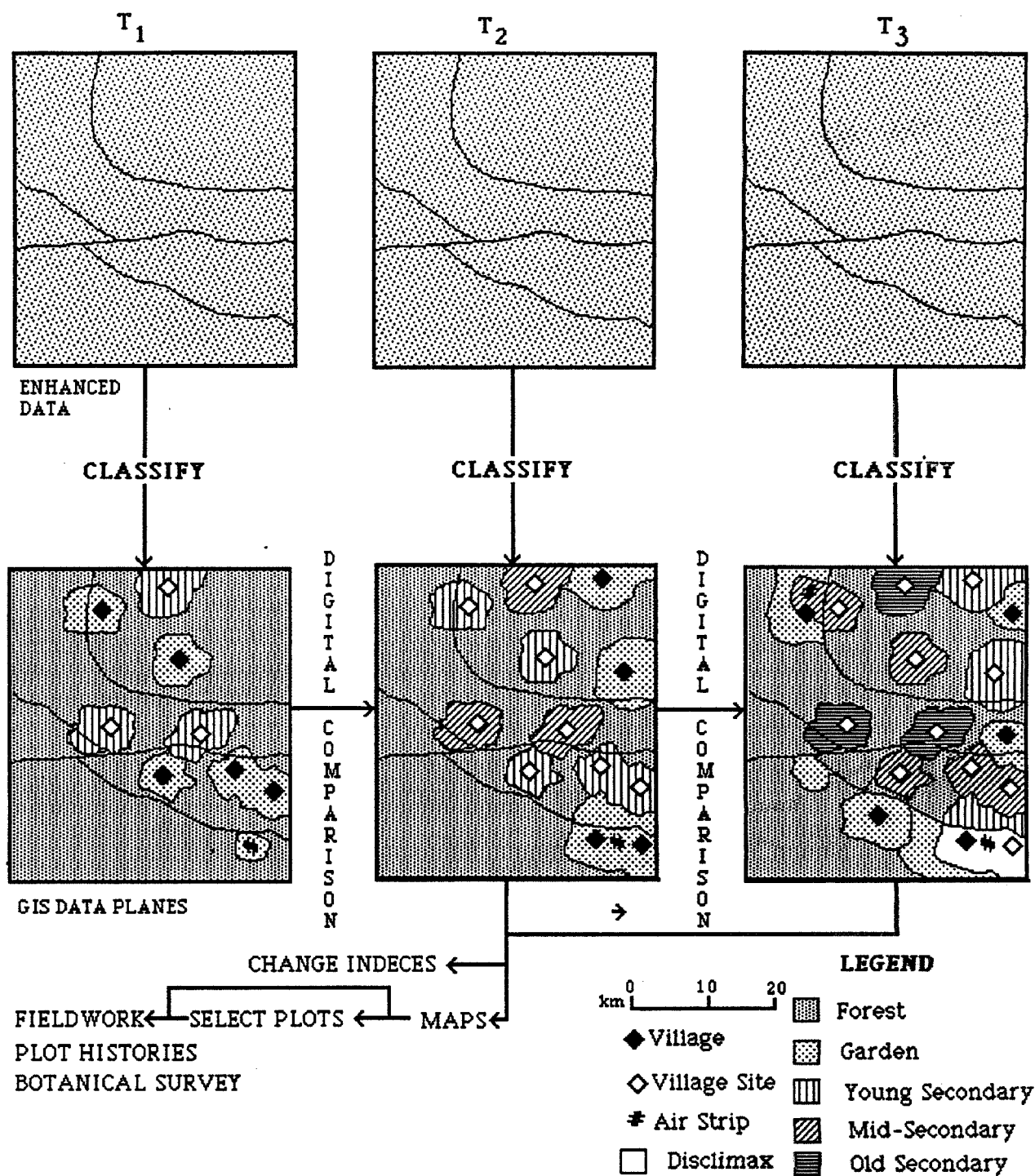


Figure 5. Change detection.

There are 14 identifiable settlements in the transect area and 4 airstrips. The extreme range of variation for the airstrip villages is explained partly by the age of the strip, whether or not produce is shipped out, and the size of the base population.

Turning to issue of the interaction of the Mountain Ok with other culture areas: Following David Hyndman's and my definition of the sphere -- reproduced in the paper -- I hypothesize that the frontiers between spheres should be marked by relatively low disturbance indices. If I pushed my transect through the Abou area to the north, the situation might look like Figure 5.

POTENTIAL SIGNIFICANCE

When anthropologists have studied or discussed people's role in environmental degradation, they have tended to adopt the traditional biological weltanschauung that sees environmental systems as enduring, monolithic objects that ought to be conserved in a (near) pristine state. Anthropological studies of swidden agriculture (e.g., Nations and Nigh, 1980; Nations and Komer, 1983) have offered useful corrections to environmentalist views regarding, for example, slash and burn agriculture, but have nevertheless emphasized the conservative nature and limited impacts of these production systems. The research described here, in contrast, places people in the environment as significant longstanding actors in inherently dynamic landscapes. It may provide additional support to the proposition that at least some tropical moist forests once considered 'virgin' are human artifacts (Covich, 1978; Lewin, 1984; Mackie, 1986). In this way, it attempts to assimilate advanced thinking in forest ecology while also advancing anthropological understanding of flux and change in human societies.

This project also hopes to advance regional studies in ecological anthropology by testing a conceptualization that emphasizes the dynamics of inter-community relations, the movement of settlements and individual people, exchange, trade, core-fringe relations and incorporates spatial and environmental factors. Remote sensing and related technologies, particularly geographic information systems, promise to solve some of the problems that have defeated previous regional studies in cultural anthropology; e.g., J.B. Watson's Eastern Highlands Micro-evolution Project (1963), such as how to organize, display, and analyze the sheer volume of data involved (see Morren, 1987).

ACKNOWLEDGEMENTS

My collaborators in this research are David Frodin, a botanist of Philadelphia, Pa., and Scott Madry, an archaeologist and photogrammetrist who is Associate Director of Rutgers' Cook College Remote Sensing Center. Preparatory research for this project was funded by the Wenner-Gren Foundation for Anthropological Research (data acquisition) and the American Philosophical Society (historical aspects).

BIBLIOGRAPHY

- B. Allen and Crittenden, R., 'Degradation and Pre-capitalist Political Economy : The Case of the New Guinea Highlands' In: Land Degradation and Society P. Blaikie and H. Brookfield (eds), London, Methuen (1987)
- A. Aubreville, 'La Foret Colonial: Les Forets de l'Afrique Occidentale Francaise' Annals de l'Academie Science Coloniale 9:1-24 (1938)
- A. Banner and Lynham, T., 'Multi-temporal Analysis of Landsat Data for Forest Cutover Mapping -- A Trial of Two Procedures' Proceedings Seventh Canadian Symposium on Remote Sensing, Winnipeg, Manitoba. (1981) pp. 233-240
- D.G. Bates and Lees, S., 'The Myth of Population Regulation' In: Evolutinary Biology and Human Social Behavior N. Chagnon & W. Irons, eds. North Scituate, MA, Duxbury, pp. 273-289 (1979)
- D.A. Boon, 'Recent Developments in Photo-interpretation of Tropical Forests' Photogrammetria 12:282-286 (1956)
- R. Bourne, Aerial Survey in Relation to Economic Development of New Countires, with Special Reference to an Investigation Carried Out in Northern Rhodesia Oxford Forestry Memoirs No. 9. Oxford, Clarendon Press (1928)
- Nancy Bowers, The Ascending Grasslands: An Anthropological Study of Ecological Succession in a High Mountain Valley of New Guinea Unpublished Ph.D. Dissertation in Anthropology, Coulumbia University (1970)
- N.V.L. Brokaw, 'Treefalls, Regrowth, and Community Structure in Tropical Forests' In: The Ecology of of Natural Disturbance and Patch Dynamics S.T.A. Pickett & P.S. White, eds. New York, Academic (1985). pp. 53-69
- Harold C. Brookfield and Hart, Doreen Melanesia: A Geographical Interpretation of an Island World London, Methuen (1971)
- Paula Brown, Highlands Peoples of New Guinea Cambridge, Cambridge University Press (1978)
- Paula Brown and Podolefsky, A. 'Population Density, Agricultural Intensity, Land Tenure and Group Size in the New Guinea Highlands' Ethnology 15:211-3 (1976)
- Susan Bulmer, 'Human Ecology and Cultural Variation in Prehistoric New Guinea' In: Biogeography and Ecology in Prehistoric New Guinea J. Gressitt, ed. The Hague, Junk. pp. 169-206 (1982)
- E. Carey, Spatial Patterns of Kenya Agriculture and their Relationship to Elevation, Soils, and Population: A Study of Grid Cell Sizes Ph. D Dissertation in Geography, Columbia University. Ann Arbor, University Microfilms (1985)
- A. Chowning, 'Physical Anthropology, Linguistics, and Ethnology' In: Biogeography and Ecology in Prehistoric New Guinea J. Gressitt, ed. The Hague, Junk. pp. 131-168 (1982)

- W.C. Clark, Place and People Berkeley, University of California Press (1971)
- C.K. Cochrane-Patrick, 'Aerial Reconnaissance Mapping in Northern Rhodesia' Geographical Review (1973)
- J. Collier, Visual Anthropology: Photography as a Research Method New York, Holt, Rinehart, and Winston (1967)
- F.P. Conant, 'The Use of LANDSAT Data in Studies of Human Ecology' Current Anthropology 19(2):382-384 (1978)
- F.P. Conant and E. Carey, 'A First Interpretation of East African Swiddening via Computer-Assisted Analysis of 3 Landsat Tapes' Machine Processing of Remotely Sensed Data West Lafayette, In, Laboratory for Applications of Remote Sensing, Purdue University (1977). pp. 36-43
- H.C. Conklin, 'Ethnographic Research in Ifugao' In: Aerial Photography in Anthropological Research E.Z. Vogt, ed. Cambridge, Harvard University Press (1974). pp. 140-159
- H.C. Conklin, Ethnographic Atlas of Ifugao New Haven, Yale University Press (1980)
- A.P. Covich, 'A Reassessment of Ecological Stability in the Maya Area: Evidence from Lake Studies of Early Agricultural Impacts on Biotic Communities' In: Pre-Hispanic Maya Agriculture P.D.
- Harrison & B.C. Turner, eds. Albuquerque, University of New Mexico Press (1978)
- R.P. Dory, 'Function and Cause' American Sociological Review 26:843-853 (1961)
- Peter Dwyer 'Prey Switching: A Case from New Guinea' Journal of Animal Ecology 51:529-42 (1982)
- William Dray, Perspectives on History London, Routledge and Kegan Paul (1980)
- W.H. Drury and Nesbitt, I.C.H., 'Succession' Journal of the Arnold Arboretum 54:331-369 (1973)
- J.I. Ebert and T.R. Lyons (eds.) 'Archaeology, Anthropology, and Cultural Resources Management' In Manual of Remote Sensing Vol. II. R.N. Colwell, J.E. Ester, & G.A. Thorley, eds. American Society of Photogrammetry (1983). pp. 1233- 1304
- J.I. Ebert, 'Remote Sensing in Archaeological Projection and Prediction' In: Quantifying the Present and Predicting the Past W.J. Judge & L. Sebastian, eds. Denver, CO, Bureau of Land Management, pp. 429-492 (1988)
- Fred Eggan, 'Social Anthropology and the Method of Controlled Comparison' American Anthropologist 56:743-763 (1954)
- M. Ehlers, G. Edwards, and P. Bedard, 'Integration of Remote Sensing with Geographic Information Systems: A Necessary Evolution' Photogrammetric Engineering and Remote Sensing 55(11):1619-1627 (1989)

J. Engleberg and Boyarsky, L.L., 'The Non-cybernetic Nature of Ecosystems' American Naturalist 114:317-324 (1979)

D.K. Feil, The Evolution of Highland Papua New Guinea Societies Cambridge, Cambridge University Press (1987)

R.T.T. Forman and Godron, M. 'Patches and Structural Components for a Landscape Ecology' BioScience 31:733-740 (1981)

R.B. Foster, 'Heterogeneity and Disturbance in Tropical Vegetation' In: Conservation Biology M.E. Soule and B.A. Wilcox, eds. Sunderland, MA, Sinauer (1980)

David G. Frodin, "The Mangrove Ecosystem in Papua New Guinea" In: Mangrove Ecosystems of Asia and the Pacific: status, Exploitation and Management C.D. Field & A.J. Dartnall, eds, Cape Ferguson, Qld., Australian Institute for Marine Science, pp. 53-63 (1987)

D. Gardner, Cult Ritual and Social Organization among the Mianmin Ph.D. Dissertation in Anthropology. Canberra, Australian National University (1981)

R.A. Hackenberg, 'Parameters of an Ethnic Group: A Method for Studying the Total Tribe' American Anthropologist 69(5):478-492 (1967)

D. Heinsdijk, 'Forest Photo-Interpretation in Surinam' Photogrammetric Engineering (1952)

R.C. Heller and J.J. Ulliman (eds) 'Forest Resource Assessments' In Manual of Remote Sensing Vol. II. R.N. Colwell, J.E. Ester, & G.A. Thorley, eds. American Society of Photogrammetry (1983). pp. 2229-2324

G.S. Hope, 'The Vegetation Changes of the Last 20,000 Years at Telefomin, Papua New Guinea' Journal of Tropical Geography 4(1):25-33 (1983)

M.S. Hopkins and Graham, A.W., 'Structural Typing of Tropical Rainforest Using Canopy Characteristics in Low Level Aerial Photography - A Case Study' In: Vegetation Classification in Australia A.N. Gillison and D.J. Anderson, eds. Canberra, Australian National University Press. (1981) pp. 53-65

Henry S. Horn, 'Succession' In: Theoretical Ecology R.M. May, ed. Philadelphia, W.B. Saunders, pp. 187-204 (1976)

C.F. Hutchinson, 'Techniques for Combining Landsat and Ancillary Data for Digital Classification Improvement' Photogrammetric Engineering and Remote Sensing 48:123-130 (1982)

D. Hyndman, 'Biotone Gradient in a Diversified New Guinea Subsistence System' Human Ecology 10(2):219-259 (1982)

D. Hyndman and Morren, G.E.B., Jr., 'The Human Ecology of the Mountain Ok: A Regional and Inter-Regional Approach' In: The Mountain Ok. B. Craig and D. Hyndman, eds. Sydney, Australia,

Oceania Monographs. (1990)

L.R. Iverson and Risser, P.G., 'Analyzing Long Term Vegetation Change Utilizing Geographic Information System and Remotely Sensed Data' *Advance in Space Research* 7:183-194 (1988)

J.R. Jensen, 'Computer Graphic Feature Analysis and Selection' *Photogrammetric Engineering and Remote Sensing* 45:1507-1666 (1979)

J.R. Jensen, *Introductory Digital Image Processing: A Remote Sensing Perspective* Englewood Cliffs, NJ, Prentice Hall (1986)

R.J. Johns, 'Vegetation' In: *Encyclopedia of Papua New Guinea*, R. Ryan, ed. Vol. II, Melbourne, Melbourne University Press (1971)

R.J. Johns, *The Vegetation of Papua New Guinea Bulolo*, Papua New Guinea, Forestry College (1977)

R.J. Johns, 'The Instability of the Tropical Ecosystem in New Guinea' *Blumea* 31:341-371 (1986)

P.L. Johnson, *Remote Sensing in Ecology* Athens, University of Georgia Press (1969)

R.C. Kelly, *Etoro Social Structure: A Study in Structural Contradiction* Ann Arbor, University of Michigan Press (1977)

D.S. Kimes, Smith, J.A., and Ransom, K.J., 'Vegetation Reflectance Measurements as a Function of Solar Zenith Angle' *Photogrammetric Engineering and Remote Sensing* 46:1563-1573 (1980)

B.M. Knauff, *Reconsidering Violence in Simple Societies: Homocide among the Gebusi of New Guinea* *Current Anthropology* 28:457-482 (1987)

E.B. Knipling, 'Physical and Physiological Basis for the Reflectance of Visible and Near-Infrared Radiation from Vegetation' *Remote Sensing of Environment* 1:155-159 (1970)

Kenneth I. Kramme, 'The Use of Geographic Information Systems for Modeling Archaeological Site Distributions' In: *Geographic Information Systems in Government* Vol. I, B.K. Opitz, ed. Hampton, VA, A. Deepak, pp. 345-362 (1986)

K.I. Kramme and Kohler, T.A., 'Geographic Information Systems: Technical Aids for Data Collection, Analysis, and Display' In: *Quantifying the Present and Predicting the Past* W.J. Judge & L. Sebastian, eds. Denver, Bureau of Land Management, U.S. Department of the Interior, pp. 493-548 (1988)

R. Lewin, 'Fragile Forests Implied by Pleistocene Pollen' *Science* 226:36-37 (1984)

Cherry Lowman, *The Structure of Impermanence: Ecological Bases of Community Growth and Decline in the Maring Region of Papua New Guinea* Unpublished Ph.D. Dissertation in Anthropol-

ogy , Columbia University (1980)

Cynthia Mackie Disturbance and Succession Resulting from Shifting Cultivation in an Upland Rainforest in Indonesian Borneo Unpublished Ph.D. Dissertation in Ecology, Rutgers University, New Brunswick, NJ (1986)

W.A. Malila, 'Change Vector Analysis: An Approach for Detecting Forest Changes with Landsat' Proceedings Machine Processing of Remotely Sensed Data, West Lafayette, Ind., Laboratory for the Applications of Remote Sensing (1980)

J.P. Malingreau, G. Stephens, and L. Fellows, "Remote Sensing of Forest Fires: Kalimantan and North Borneo in 1982-83' *Ambio* 14(6):314-321 (1985)

Bonnie McCay, 'Optimal Foragers or Political Actors? Ecological Analyses of a New Jersey Fishery' *American Ethnologist* 8(2):356-82 (1981)

Mervyn J. Meggitt, *The Lineage System of the Mae-Enga of New Guinea* Edinburgh, Oliver & Boyd (1965)

R.G. Miller, 'The Interpretation of Tropical Vegetation and Crops on Aerial Photographs' *Photogrammetria* 16(3):232-240 (1960)

Sally Falk Moore, 'Epilogue: Uncertainties in Situations, Indeterminacies in Culture' In: *Symbol and Politics in Communal Ideology* S.F. Moore & B.G. Myerhoff, eds. Ithaca, Cornell University Press, pp. 210-239 (1975)

G.E.B. Morren, Jr., *Settlement Strategies and Hunting in a New Guinea Society* Ph.D. Dissertation, Columbia University, Ann Arbor, University Microfilms (1974)

G.E.B. Morren, Jr., 'From Hunting to Herding: Pigs and the Control of Energy in Montane New Guinea' In: *Subsistence and Survival: Rural Ecology in the Pacific*. ed. by Timothy Bayliss-Smith and Richard Feachem. London, Academic Press. pp. 272-315 (1977)

G.E.B. Morren, Jr., 'Seasonality among the Miyanmin' *Mankind* 12:1-12 (1980)

G.E.B. Morren, Jr., 'A Small Footnote to the "Big Walk": Development and Change among the Miyanmin of Papua New Guinea' *Oceania* LII(1):39-65 (1981)

G.E.B. Morren, Jr., 'Warfare on the Highland Fringe of New Guinea: The Case of the Mountain Ok' In: *Warfare, Culture and Environment* B. Ferguson, ed. New York Academic Press. pp. 169-207 (1984)

G.E.B. Morren, Jr., 'CA* Comment on Knauff: Reconsidering Violence in Simple Human Societies, *Current Anthropology* (August-October, 1987

G.E.B. Morren, Jr., *The Miyanmin: Human Ecology of a Papua New Guinea Society*, Iowa State University Press (1986)

G.E.B. Morren, Jr., 'Review of J.B. Watson: Tairora Culture: Contingency and Pragmatism' *American Ethnologist* 14(4):808-9 (1988)

G.E.B. Morren, Jr., 'Mammals of the East Miyanmin Area, Telefomin District, Sanduan Province, Papua New Guinea, with Notes on Folk Knowledge and Taxonomy' *Science in New Guinea* 15(3) (1988)

G.E.B. Morren, Jr. and Hyndman, D., 'The Taro Monoculture of Central New Guinea' *Human Ecology* 15(3):301-315 (1988)

G.P. Murdock, *Ethnographic Atlas* Pittsburgh, University of Pittsburgh Press (1967)

J.D. Nations and Nigh, R.B., 'The Evolutionary Potential of Ladandon Maya Sustained-Yield Tropical Forest Agriculture' *Journal of Anthropological Research* 36(1):1-30 (1980)

J.D. Nations and Komer, D.I., 'Central America's Tropical Rainforest: Positive Steps for Survival' *Ambio* 12(5):232-238 (1983)

R. Nelson and Holben, B., 'Identifying Deforestation in Brazil Using Multi-Resolution Satellite Data' *International Journal of Remote Sensing* 7:429-448 (1986)

Sherry B. Ortner, 'Theory in Anthropology Since the Sixties' *Comparative Studies in Society and History* 26:126-166 (1984)

K. Paijmans, 'Typing of Tropical Vegetation by Aerial Photographs and Field Sampling in Northern Papua' *Photogrammetria* 21:1-25 (1966)

K. Paijmans, 'Land Evaluation by Air Photo Interpretation and Field Sampling in Australian New Guinea' *Photogrammetria* 26:77-100 (1970a)

K. Paijmans, 'An Analysis of Four Tropical Rainforest Sites in New Guinea' *Journal of Ecology* 58:77-101 (1970b)

S.T.A. Pickett, 'Non-equilibrium Coexistence of Plants' *Bulletin of the Torrey Botanical Club* 107(2):238-248 (1980)

S.T.A. Pickett, 'Differential Adaptation of Tropical Species to Canopy Gaps and its Role in Community Dynamics' *Tropical Ecology* 24:68-84 (1983)

A.R. Radcliff-Brown, *Structure and Function in Primitive Society* London, Cohen & West (1952)

Roy A. Rappaport, *Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People* New Haven Yale University Press (1968)

P. Reining, 'Utilization of ERTS-1 Imagery in Cultivation and Settlement Site Identification and Carrying Capacity Estimates in Upper Volta and Niger' Springfield, VA., National Technical Infor-

mation Service (1973)

C.R. Robbins, 'Northern Rhodesia: An Experiment in the Classification of Land with the Use of Aerial Photography' *Journal of Ecology* 22(1):88-105 (1934)

R.G. Robbins, 'Montane Formations in the Central Highlands of New Guinea' *Proceedings of the Symposium on Humid Tropics Vegetation Tjawi, Indonesia, UNESCO*. pp. 176-196 (1958)

J.R. Runkle, 'Disturbance Regimes in Temperate Forests' In: *The Ecology of Natural Disturbance and Patch Dynamics* S.T.A. Pickett and P.S. White, eds. New York, Academic Press (1985)

H.J. Rutz, 'Individual Decisions and Functional Systems: Economic Rationality and Environmental Adaptation' *American Ethnologist* 4(1):27-41 (1977)

T.S. Schorr, 'A Bibliography and Historical Sketch' *Aerial Photography in Anthropological Research* Cambridge, E.Z. Vogt, ed., Harvard University Press (1974), pp. 163-188

C. Schire, ed., *Past and Present in Hunter Gatherer Studies* Orlando, FL, Academic Press (1984)

T. Schwartz, 'Systems of Areal Integration: Some Considerations Based on the Admiralty Islands of Northern Melanesia' *Anthropological Forum* 1:56-97 (1962)

P. Sillitoe, *Roots of the Earth: Crops in the Highlands of Papua New Guinea* Manchester, England, Manchester University Press (1983)

Daniel Simberloff, 'A Succession of Paradigms in Ecology: Essentialism to Materialism and Probabilism' *Synthese* 43:3-39 (1980)

J. Stanhope, 'Patterns of Fertility and Mortality in Rural New Guinea' *New Guinea Research Bulletin* No. 34. Canberra, Australian National University Press (1979)

A. Steensberg, *New Guinea Gardens: A Study of Husbandry with Parallels in Prehistoric Europe* London, Academic Press (1987)

A.H. Strahler, Logan, T.L., and Bryant, N.A., 'Improving Forest Cover Classification Accuracy from Landsat by Incorporating Topographic Information' *Proceedings International Symposium on Remote Sensing of the Environment*. Ann Arbor, Environmental Research Institute of Michigan. (1978) pp. 927-942

P. Swadling, *How Long Have People Been in the Ok Tedi Impact Region Waigani, Papua New Guinea* National Museum Record No. 8 (1983)

E.G. Swellengrebel, 'On the Value of Large Scale Aerial Photographs in British Guiana Forestry' *Empire Forestry Review* 38(1):54-64 (1959)

R.F. Tomlinson, 'Geographic Information Systems — A New Frontier' *Proceedings International Symposium on Spatial Data Handling, Zurich, Switzerland*. (1984) pp. 1-14

- J.R.G. Townsend and Justice, C.O., 'Analysis of the Dynamics of African Vegetation Using the Normalized Difference Vegetation Index' *International Journal of Remote Sensing* 11:1435-1445 (1986)
- C.J. Tucker, Townsend, J.R.G., and Goff, T., 'African Land-cover Classification Using Satellite Data' *Science, New York* 227:369-375 (1985)
- A.P. Vayda, *War in Ecological Perspective: Persistence, Change and Adaptive Processes in Three Oceanian Societies* New York, Plenum (1976)
- A.P. Vayda, 'Progressive Contextualization: Methods for Research in Human Ecology' *Human Ecology* 11:265-281 (1983)
- A.P. Vayda, 'Holism and Individualism in Ecological Anthropology' *Reviews in Anthropology* 13(4):295-313 (1986)
- A.P. Vayda, C.J.P. Colfer, and M. Brotokusumo, 'Interactions between People and Forest in East Kalimantan' *Impact of Science on Society* 30:179-190 (1980)
- A.P. Vayda, and McCay, B. 'New Directions in Ecology and Ecological Anthropology' *Annual Review of Anthropology* 4:293-306 (1975)
- A.P. Vayda, and McCay, B. 'Problems in the Identification of Environmental Problems' In: *Subsistence and Survival: Rural Ecology in the Pacific*. ed. by Timothy Bayliss-Smith and Richard Feachem. London, Academic Press. pp. 411-418 (1977)
- A.P. Vayda, and A. Sahur, 'Forest Clearing and Pepper Farming by Bugia Migrants in East Kalimantan: Antecedents and Impact' *Indonesia* 39:93-110 (1985)
- E.Z. Vogt, 'Aerial Photography in Highland Chiapas Ethnography' In: *Aerial Photography in Anthropological Research* E.Z. Vogt, ed. Cambridge, Harvard University Press (1974). pp. 57-77
- Eric Waddell, *The Mound Builders: Agricultural Practices, Environment and Society in the Central Highlands of New Guinea* Seattle, University of Washington Press (1972)
- Eric Waddell, 'How the Enga Cope with Frost: Responses to Climatic Perturbations in the Central Highlands of New Guinea' *Human Ecology* 3:249-272 (1975)
- James B. Watson, 'From Hunting to Horticulture in the New Guinea Highlands' *Ethnology* 4:295-309 (1965)
- James B. Watson, 'Pigs, Fodder and the Jones Effect in Post Ipomoean New Guinea' *Ethnology* 16:57-69 (1977)
- James B. Watson, *Tairora Culture: Contingency and Pragmatism* Seattle, University of Washington

Press (1983)

James B. Watson, 'The Precontact Northern Tairora: High Mobility in a Crowded Field' In: *Circulation in Population Movement* M. Chapman & R.M. Prothero, eds. London, Routledge & Kegan Paul. pp 15-38 (1985)

D.R. White, 'Standard Cross Cultural Codebook, I-V' *World Cultures* 1(1,2,4); 2(2,3) (1985-86)

K.J. White, 'The Effect of Natural Phenomena on the Forest Environment' Presidential Address to the Papua New Guinea Society (1975)

D.S. Wilkie and J.T. Finn, 'A Spatial Model of Land Use and Forest Regeneration in the Ituri Forest of Northeastern Zaire' *Ecological Modeling* 41:307-323 (1988)

D.S. Wilkie, 'Performance of a Backpack GPS in a Tropical Rain Forest' *Photogrammetric Engineering and Remote Sensing* 55(12):1747-1749 (1989)

G.M. Woodwell, R.A. Houghton, T.A. Stone, and A.B. Park, 'Change in the Area of Forests in Rondonia, Amazon Basin, Measured by Satellite Imagery' In: *The Changing Carbon Cycle* J. Trabalka D. Reichle, eds. New York, Springer-Verlag (1986)

G.M. Woodwell, R.A. Houghton, T.A. Stone, and R.F. Nelson, and W. Kovalick, 'Deforestation in the Tropics: New Measurements in the Amazon Basin Using LANDSAT and NOAA Advanced Very High Resolution Radiometer Imagery' *Journal of Geophysical Research* 92(D2):2157-2163 (1987)

**"VERY-TO-BARELY" REMOTE SENSING OF PREHISTORIC FEATURES
UNDER TEPHRA IN CENTRAL AMERICA**

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

Payson D. Sheets•

S9-43

201796

P 12

ABSTRACT

A wide variety of remote sensing instruments have been utilized to attempt to detect archaeological features under volcanic ash in Central America. Some techniques have not been successful, such as seismic refraction, for reasons that are not difficult to understand. Others have been very successful, and provide optimism for archaeologists witnessing the destruction of unburied sites throughout Central America. The sudden burial of buildings, gardens, and footpaths by volcanic ash can preserve them extremely well, providing a rich data base for understanding human life and culture at certain points in time.

INTRODUCTION

The objective of this chapter is to compare the use of a wide variety of optical and digital sensing devices as they have been applied to archaeological problems in Central America. All were utilized in tropical wet environments, and all were tested for their abilities to penetrate tephra and locate prehistoric features as anomalies.

Tephra is the term for all volcanic materials blown through the air during explosive eruptions, and thus includes volcanic ash, pumice, lapilli, lava bombs, and so forth, but it excludes lava. Tephra has the fortunate property of being relatively uniform, and thus creates an isotropic matrix except where prominent archaeological features intrude. Most instruments were used in an attempt to detect the contrast between the archaeological feature and the matrix, or the effect of the feature on the matrix.

The study areas, the Arenal area of northwestern Costa Rica and the Ceren area of central El Salvador, are both in tropical moist environments. The Arenal area ranges in elevation from 400 to 900 meters, and mean precipitation figures are 1300 mm in the extreme west to over 6000 mm in the east. Ceren is at 450 meters, and has a mean precipitation of about 1700 mm.

Both study areas have received numerous tephra deposits over the past few thousand years. Arenal Volcano has erupted 10 times since its birth 4000 years ago, and the Ceren area has received tephra from four eruptions: Ilopango in AD 175, Laguna Caldera c. AD 600, Boqueron sometime between AD 800 and 1200, and Playon in AD 1658.

The cases are organized from more remote to less remote sensing. The question of scale is with us in all applications, as instruments vary considerably in their effectiveness to detect items of

-
- Anthropology Department, University of Colorado, Boulder, CO 80309-0233

PAGE 166 INTENTIONALLY BLANKST

varying size at different depths of burial.

Unfortunately, Central America has witnessed a sad destruction of so many archaeological sites, for so many reasons. The looting of sites for saleable items, so common in the first half of this century, has increased steadily. The tropical climate, with high rainfall, acid soils, and very high rates of bioturbation, is inimical to preservation. In many areas the majority of archaeological sites are so devastated that they are no longer worth excavating. The record of human activity at so many sites has been largely destroyed. However, sudden burial of sites in prehistoric times by things such as tephra blankets can provide a wealth of information to at least partially compensate for the losses due to the above mentioned factors. One of our wishes is to develop methods to detect unusually well-preserved sites and features under tephra deposits, to provide islands of knowledge amid seas of devastation.

Costa Rica

This section on remote sensing in Costa Rica is organized in terms of the distance between instrument and target, beginning with the most distant. The part on aircraft-mounted sensors is organized in terms of the utility in detecting anomalies that turned out to be footpaths, from the most useful to the least. Certainly the most remotely sensed data base resulted during this research was the optical medium format photography taken of earth by US astronauts while they were on the moon. Their Hassleblad photographs are of exceptional beauty, but they are of limited utility in archaeological applications, as I have difficulty in locating either Costa Rica or El Salvador.

Of greater utility is the satellite imagery taken of northwestern Costa Rica by Landsat MSS and TM. The strong ecological gradient shows very clearly in both, from only 1300mm in the west to over 6000 mm in the east. Vegetation ranges from a tropical wet-dry sparse forest to very high-biomass tropical rainforest in the east. Also, the TM imagery was useful in differentiating the components of the 1968 eruption of Arenal, the key to understanding the prehistoric eruptions. The lava flows, the pyroclastic flows, the area damaged by vertical airfall deposits, and the gas plume are all clearly visible in the imagery.

The data that were the most useful for archaeological purposes were collected from aircraft-mounted instruments. Aircraft elevations ranged from a couple thousand feet to 30,000 above terrain. There is an indirect relationship between the utility of the imagery and the distance between instrument and the ground. Lower is better for our purposes, particularly for smaller or more narrow features. That applies to both digital and optical instruments.

Color Infrared Photography

The lower elevation color infrared (CIR) photography was the most effective of aircraft-gathered data, because of its fine resolution and sensitivity to subsurface features that affect plant growth (Figs. 1 & 2). Tom Sever was the first to notice the linear anomalies and suspect that they might be prehistoric features. Upon excavation, the stratigraphy of dated tephra layers allowed for a secure dating of the features to the prehistoric era. Tracing the evidence of erosion from path use and the burial and preservation of the path by tephra deposits in trenches excavated across the anomalies allowed for an approximate dating of the path's beginning and ending.



Figure 1. Color infrared aerial photograph east of Tilaran, Guanacaste, Costa Rica, from NASA aircraft at low elevation. Confirmed footpaths are visible as faint darker lines trending from upper right corner toward center. Stennis.

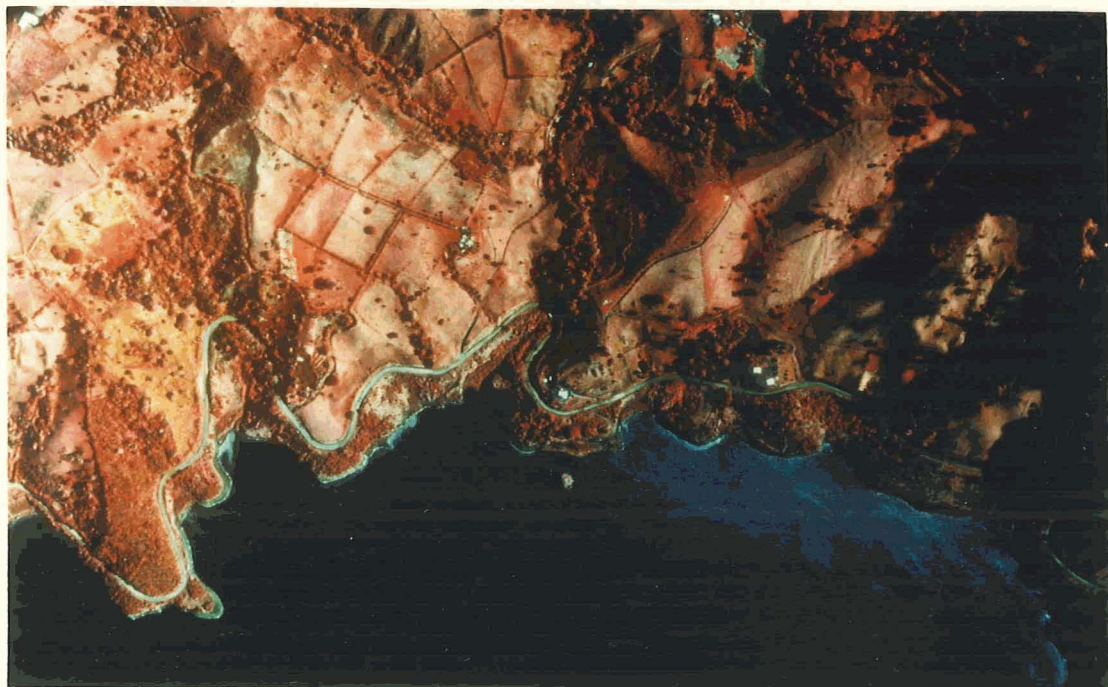


Figure 2. Color infrared photograph of shore of Lake Arenal. The shore is dotted with prehistoric villages ranging in age from before 2000 BC to AD 1500. A linear anomaly that might be a prehistoric footpath can be seen just to the right of the center, angling down from upper right to lower left. If confirmed, it will link the Gp150 cemetery with the G-156 village along the lakeshore in the center of the photograph. Stennis.

Pasture grasses, with their roots penetrating one to 1.5 meters, grow better along the paths, and thus show up as a darker red line in the CIR photography. However, other features can be mistaken for prehistoric paths, and ground verification by excavation and microstratigraphic examination are essential. In one instance a linear anomaly appearing very much like the confirmed prehistoric paths was detected and excavated, and it clearly was historic as it had formed as a depressed line after the c. AD 1500 and before the 1968 tephra from Arenal Volcano (Units 10 and 20 respectively). Later checking with local residents identified it as an oxcart path entrance to a ranch that was in use early in the 20th century.

The paths evidently formed when people began walking in a line up or down slope. Their walking caused compaction along a line, discouraging plant growth and causing a channel for rainwater to concentrate and erode. In many places that erosion was minimal, only a meter or less deep, but on a few steep slopes it reached over four meters in depth. And, as the path eroded downward, it eroded laterally. Lateral erosion often would extend only a meter or two out from each side of the path, but sometimes would extend as far as five meters or more on each side. Tephra deposited after path abandonment not only provided dating information for cessation of path use, it also assisted in preserving the features. The film used was color infrared transparency, with 9x9" negative size. Both transparencies and prints were very effective in divulging linear anomalies that proved to be prehistoric footpaths. Enlargements to 1x1 meter and larger were also useful, and recorded tremendous detail. Individual clumps of pasture grass could be seen, and when the plane flew over the town of Tilaran, the individual faces of people coming outside to see the plane fly over low numerous times were visible. The sequential overlaps of images were useful when viewed in stereo, as the degree of slope played a major role in footpath formation. Other factors were precipitation (mean rainfall ranges from 1300 to over 6000 mm from west to east) and intensity and duration of use.

Black-and-white Aerial Photography

After recognizing the utility of the CIR 9x9's, we explored the archives of the Instituto Geografico and found the black-and-white 9x9" photogrammetric negatives used for topographic mapping (Fig. 3.). A full set of overlapping 9x9" prints were purchased, at low cost (about \$1 each), and some enlargements of a quadrant (3x3") were made to about 1x1 meter size. The resolution generally is sufficiently good that little grain is visible even when a quadrant is amplified that much. Most of the prehistoric paths detected in the CIR data were also visible in the b/w data, but not as prominently, and lighting is more critical. Raking sunlight is more useful than direct illumination. A real advantage to most archaeological projects is that most areas of the world have been covered by such photography, and they can be obtained for archaeological research with relatively little difficulty and expense. In the US, the US Geological Survey and the Soil Conservation Service have photogrammetric image archives. In other countries the Geographic Institute or its equivalent has negative archives. Coverage of areas where civil wars are being fought may be more difficult to obtain, but in most cases it can be done with the assistance of government officials.

Color Aerial Photography

Regular color aerial photography was obtained using a special high-speed motor driven 35mm camera. These can be blown up to 8x10" prints, but begin to lose detail when more greatly enlarged. The film was sensitive both to vegetation variation over and beyond the paths and to relief differences. With the latter, the angle of view and the angle of the sun relative to the hillslope were impor-

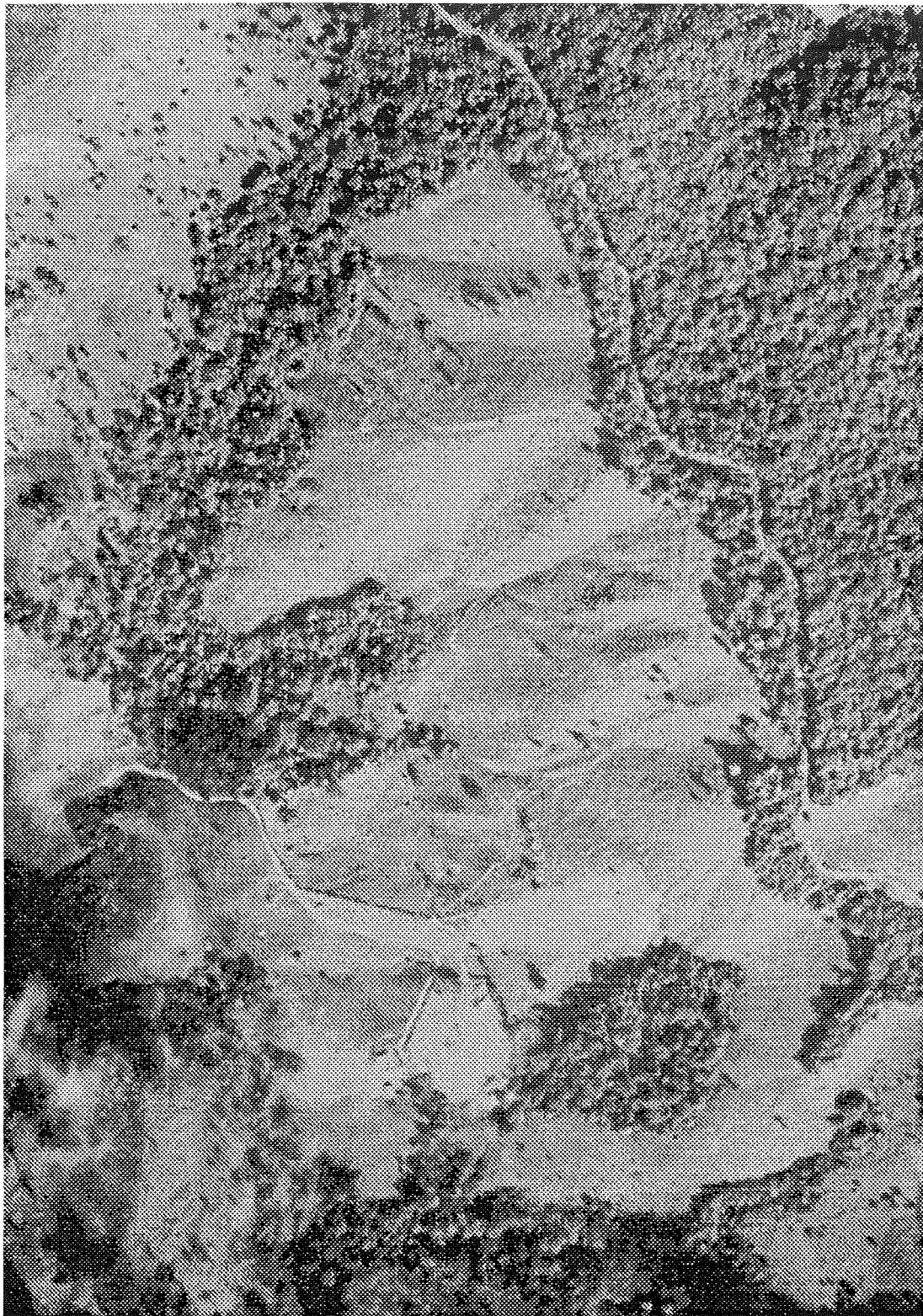


Figure 3. Black-and-white aerial photography from the Costa Rican Instituto Geografico. The G-150 cemetery is on the right center, and a path can be seen heading away from it toward the upper right, making a bend and forking into two paths. The two paths head down into a forested gully and emerge as two paths on the far side. Toward the bottom right three paths can be seen heading down into a patch of trees where people obtained water from a spring. The spring still functions and provides water for the dairy cattle ranch.

tant, as with the b/w photography. The resolution is not quite as good as with the two photogrammetric techniques discussed above.

Thermal Infrared Multispectral Scanner

The Thermal Infrared Multispectral Scanner (TIMS) was the most effective of the digital instruments utilized in the research. Because it was flown at relatively low elevations, a few thousand feet above terrain, its resolution was down to a few meters, and it quite easily detected the previously confirmed prehistoric footpaths connecting the G-150 cemetery with the spring to the south and the path leading out of the cemetery toward the north (Fig. 4). Evidently, the thermal differentials of the paths relative to their surrounding area were detected. Apparently that was done by the erosion leaving a channel that was differentially warmed by the sun, with the side receiving more direct illumination being hotter than the side that was more shaded. The relative scale of the target feature and the resolution of the low-flying TIMS instrument were appropriate.

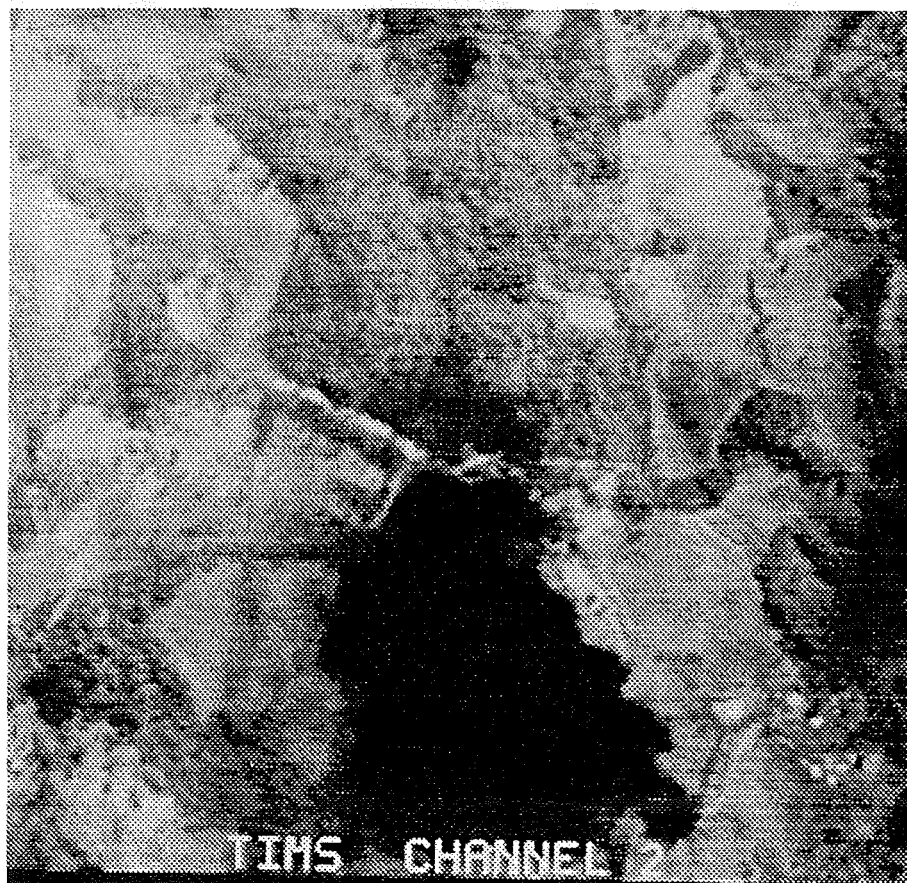


Figure 4. Thermal Infrared Multispectral Scanner image of the G-150 Silencio cemetery (center) and the paths leading to the spring to the right.

Radar

A side-looking airborne radar was also flown, and it was highly effective in detecting linear anomalies in pastures, secondary growth, and mature rainforest (Fig. 5). In fact, its abilities to

record linear anomalies far exceed our abilities to inspect on the ground and excavate. A personal drawback of the radar is my difficulties in understanding the interaction of the radar waves with small specific elements of the vegetation and landforms. Fortunately, large features are understandable in the radar imagery, such as contemporary roads, property boundaries, rivers, lakes and hills. However, the scale of archaeological features in the area is smaller than the scale of recognizable features in the radar data, at least to date. The effective use of radar in archaeological application requires attention to appropriate scales of target and instrument as well as a thorough program of ground verification and excavation where necessary.



Figure 5. Radar image of the G-150 Silencio cemetery in center. The light colored area to the right is a mature tropical rainforest, and linear anomalies are visible running in various directions. One has been confirmed as a historic road; the others are of unknown nature or origin.

Lidar

The Lidar instrument, which measures distance by travel time of a laser beam, was flown on the low level overflights. It recorded elevation of terrain as a string of point measurements. When it passed over a footpath that still affected topography, i.e. where the erosional channel caused by the

footpath has a surface expression visible today, it would record a dip. The dips were only a meter to a few meters deep, a few meters wide, and the Lidar instrument quite accurately recorded them. A problem with Lidar is that it is recovering data in a line rather than over an area, so a large number of parallel flight lines are necessary to generate useful microtopographic data. Another problem is that the research area, with its gently rolling terrain and high rainfall, is interlaced with small natural erosional channels, and it is more difficult to distinguish natural from cultural erosional features in the Lidar than in the other data bases. For these kinds of features in this environment it is not a very efficient discovery technique.

Parenthetically, it is somewhat similar to an informal technique that we call "synchronous head bobbing." For many weeks in 1984 I drove an excavation crew across a pasture to do excavations at site G-151, before we knew that a prehistoric footpath passed in that area. The pasture grasses were rather thick, and hid a dip in the middle of the pasture. The dip was sufficient to cause all heads in the jeep to bounce back and forth. We wondered what it was but it never crossed our minds that it was a prehistoric footpath which later was detected by all the aerial photography as well as TIMS and Lidar. From then on we paid attention to a synchronous bobbing of heads while driving across pastures, but we were not able to turn this ancient technique into a full-blown feature detection procedure.

El Salvador

Geologically, topographically, and climatically El Salvador shares many characteristics with Costa Rica. Archaeologically, however, El Salvador witnessed the growth of large populations, complex societies, participation in long-distance trade networks, and the construction of large buildings. In contrast, prehistoric Costa Rican societies generally were successful in maintaining small populations that were politically and economically self-sufficient and stable over centuries or millennia.

The focus of this section is on the Ceren site, located on the left bank of the Rio Sucio at 450 meters in elevation. It was a village or town of unknown size some 1400 years ago when it was buried by 4 to 7 meters of tephra from Laguna Caldera Volcano. The volcano and associated vents are only a mile to the north and east, and they deposited a series of 14 beds in rapid succession over the site. Some were direct airfall deposits while others were pyroclastic flows or base surges. The deposits sealed the structures and their contents, eliminating the ravages of weathering and erosion, gradual abandonment, looting, and other factors. That allows for a much more detailed study of household contents and activities than is usually possible. However, that depth of burial creates a problem in discovery of structures. The combination of airfall and flow tephra emplacements tends to smooth the microtopography and hide buried buildings, so that there is no evidence on the present surface to indicate the location of buried structures.

Three geophysical instruments have been used to date to search for subsurface anomalies that could be buried structures. Two of the three, resistivity and ground-penetrating radar, have been quite successful, but seismic refraction has barely been able to detect the buried structures. Loker (1983) summarized the first two seasons of geophysical explorations at Ceren, and Spetzler (1989, 1990) discussed the two most recent seasons of research with resistivity.

Seismic Refraction

Seismic refraction is a technique utilized for detecting sizeable anomalies at considerable depths, often using dynamite as an energy source and detecting the seismic waves returning from underground interfaces with geophones. Instead of a large explosion we used a sledge hammer striking a metal plate on the ground as the source of seismic energy. Seismic refraction has the advantage of being very portable, but the data were difficult to interpret. The expectation was that a house floor would conduct and refract the seismic waves more rapidly than the surrounding tephra. The geophones were laid out in a line or fan and the data were inspected for any early arrivals of the energy waves. Although some prehistoric structures may have affected arrivals, and thus been detected by the seismograph, no case was very clear, and interpretive uncertainties abounded. We have no intentions of using seismic refraction again, given the success of the two other instruments.

Ground-penetrating Radar

A ground-penetrating radar unit transmits radio waves and receives them as they bounce back from interfaces. Both their travel time and their configuration allow for a two dimensional subsurface profile to be recorded (Fig. 6). The high-frequency radio waves are reflected more strongly from an interface from a loose to a dense material than vice versa. At Ceren house floors have been found to be strong radar reflectors, as they are made of dense prepared clay and covered by a more loose tephra. Also, the floors elevated on tops of platforms causes the lower tephra units to bow up



Figure 6. Ground-penetrating radar unit in operation at Ceren, El Salvador. Data were taken along 100m traverses throughout the 1 hectare study area. An advantage of the oxcart is the constant distance to the ground surface and the uniform rate of travel.

over structures, which is easily detectable in the imagery (Fig. 7). Moist clay attenuates the radar energy rapidly. Although the Ceren area receives some 1700mm of precipitation annually, the first clay-laden layer one encounters in excavating down is below the target features, fortunately. The wavelength of radar is much shorter than seismic refraction, and therefore is more appropriate to detection of relatively small features at shallow depth.

Resistivity

A resistivity instrument measures the ability of the ground to conduct (or resist) electricity (Fig. 8). Measurements are taken at regular intervals to establish the "background" and look for anomalies. Both the materials themselves and their moisture content are important in their degree of resistivity. Fortunately, the tephra layers are sufficiently coarse at Ceren to allow resistivity surveying, even after a strong rain. A dense upper soil level that has become wet from rain can "short out" the electricity, making detection of subsurface anomalies impossible. Depth of penetration is proportional to spacing of the rods (almost 1:1), and the intervals between measurements can be adjusted to size of features being sought. A measurement, in ohm-meters, at a particular location should not be taken to be a precise point measurement, as the instrument is measuring a broad zone, like a subsurface hammock strung below the rods.

Buried structures have been found to create an M-shaped profile (Fig. 9) in the resistivity data (Loker 1983). As the instrument approaches a buried structure the resistivity increases, perhaps because the tephra layers are sloping away from it and shedding moisture. On top of the structure the resistivity decreases, perhaps because the flatlying tephra layers and especially the house floor retain moisture. In addition, the dense clay of a house floor should conduct electricity readily. We

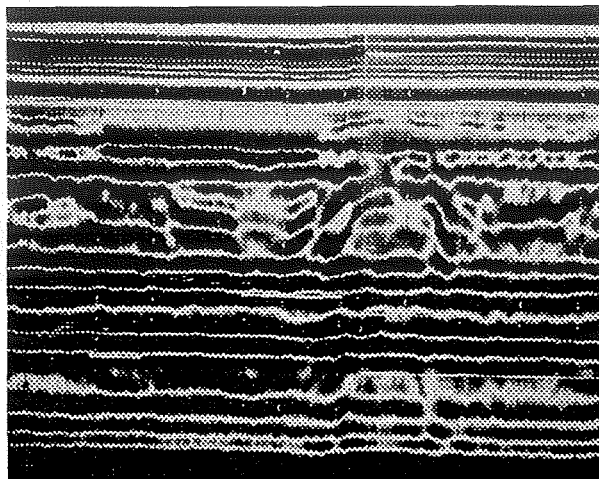


Figure 7. Raw radar data as recorded immediately during traverse by graphic recorder in oxcart. Scale from top to bottom is about 10 meters and from side to side is 55 meters; vertical timing marks indicate 5 meter distances along traverse. The tephra levels bow up over a prominent feature right of structure, Str. 2, and the floor of the structure can be seen as a strong reflector.

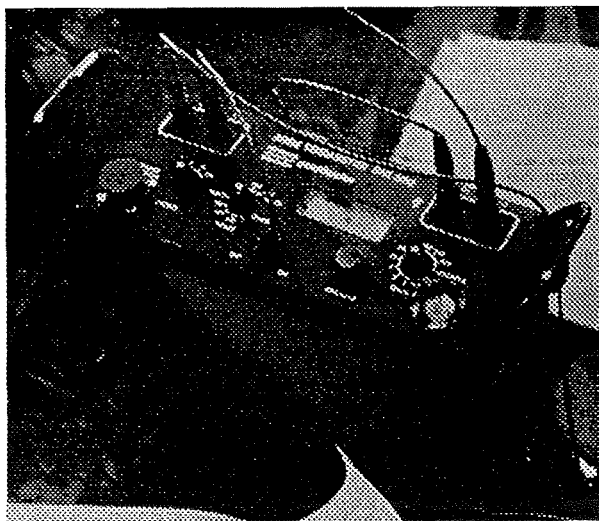


Figure 8. Resistivity instrument giving values in ohm-meters of resistance of subsurface matrix to electricity.

have not been able to detect the smaller buildings at Ceren with resistivity, but the larger buildings have been successfully detected and confirmed with excavations. Larger in this case means at least 3x3 meters, set up on a platform at least a meter above the surrounding ground surface. The largest structure detected by resistivity measures 5x8 meters, and extends 3.5 meters above the surrounding ground surface. Household 1 was discovered by the bulldozer but Households 2 and 4 were found with resistivity and radar, as was the communal building (Str. 3). More recent resistivity research, done in the past two years, has encountered numerous anomalies (Spetzler and Tucker 1989, Spetzler 1990). Although ground truthing excavations are not completed, it appears that some are natural and some are cultural.

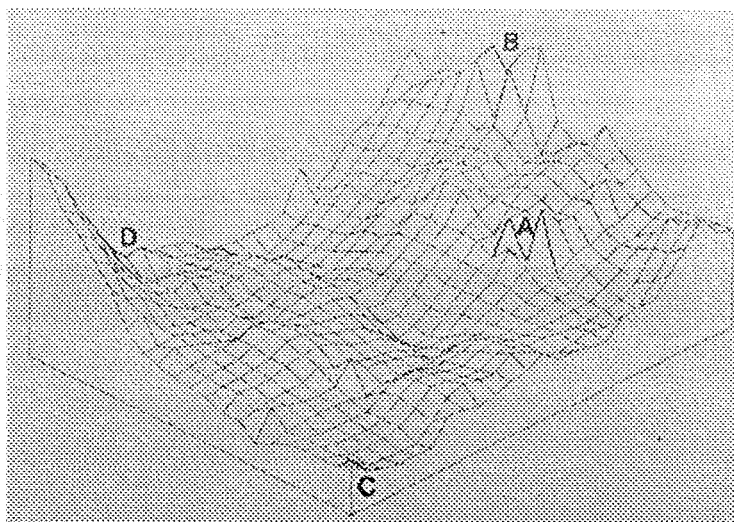


Figure 9. Resistivity data plotted on 3-d software. All M-shaped anomalies have been confirmed as prehistoric structures by excavations.

A knowledge of the volcanic substrates at Ceren suggests that magnetic methods would be difficult to employ. The large number of coalescing lava flows under the surface, each with its own frozen magnetic field, would cause such complexities for a magnetometer that it would be difficult to detect small archaeological features.

An informal, visual technique we have developed out of empirical experience to detect probable buried structures at Ceren is following tephra topography. Smaller buried structures cause the lower most tephra units (1 through 3) to bow upward, and the larger structures cause tephra units as high in the sequence as 8 or 10 to bow upward. Thus, while removing the tephra layers we are constantly examining the deposits for dip and strike or any undulation. Generally we have been correct in interpreting the tephra bulges as structures, but a relatively small bulge to the south of Structure 4, initially thought to be a small structure, turned out to be a buried clump of large agave plants in a garden.

CONCLUSIONS

The most useful remote sensing techniques in these studies were color infrared aerial photography for detecting footpaths in Costa Rica and ground-penetrating radar and resistivity for detecting buried buildings in El Salvador. It would be difficult to overemphasize the importance of scale and target matrix in making decisions regarding appropriate instruments for particular objectives. Instruments may be very successful in certain applications, for instance, seismic refraction for detecting large geological features at considerable depth, but they may be difficult to adjust to smaller features or shallow penetration. On the other hand, if the properties of the matrix and of the target features are studied, so that their contrasts can be sought, the chances of finding archaeological features increase considerably.

The question of appropriate scale was handled by staying close to the targets in both cases. In El Salvador the instruments were moved along or on the ground surface at regular intervals. In Costa Rica the instruments which yielded the most useful data were flown at low elevations above the ground surface.

ACKNOWLEDGEMENTS

My greatest debt of gratitude is owed, of course, to Dr. Tom Sever at Stennis Space Center. Without him, my knowledge of remote sensing would be very limited indeed. I am grateful to Hartmut Spetzler, Randolph Ware, and William Loker for geophysical remote sensing in El Salvador. Both projects were supported by grants from the US National Science Foundation. Their support is greatly appreciated.

REFERENCES

Loker, William

1983 "Recent geophysical explorations at Ceren" In P. Sheets ed. *Archaeology and Volcanism in Central America: The Zapotitan Valley of El Salvador*. Pp. 254-274.

Spetzler, Hartmut, and David Tucker

1989 "1989 Geophysical Research at Ceren." In P. Sheets and B. McKee eds. *1989 Archaeological Investigations at the Ceren Site, El Salvador: A Preliminary Report*. MS, Anthropology, University of Colorado, Boulder.

Spetzler, Hartmut

1990 "Resistivity Survey of Lot 189B, Ceren, El Salvador, 1990" In Payson Sheets and Brian McKee eds *Preliminary Report of the 1990 season, Ceren, El Salvador*.

PROTECTING RAIN FORESTS AND FORAGER'S RIGHTS USING LANDSAT IMAGERY

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

David S. Wilkie*

510-43
201797
p 12

ABSTRACT

Creating rain forest reserves is vital given the global decline in biodiversity. Yet, the plants and animals that will be protected from untrammelled commercial exploitation within such reserves constitute essential resources for indigenous foragers and farmers. Balancing the needs of local subsistence level populations with the goals of national and international conservation agencies requires a thorough understanding of the mutual impacts that arise from the interaction of park and people. In the Ituri forest of Zaïre, LANDSAT TM image analysis and GPS ground truth data were used to locate human settlements so that boundaries of the proposed Okapi Reserve could be chosen to minimize its impact on the subsistence practices of the local foragers and farmers. Using satellite imagery in conjunction with cultural information should help to ensure traditional resource exploitation rights of indigenous peoples whilst simultaneously protecting the largest contiguous area of undisturbed forest.

Keywords: rainforest, conservation, Zaïre, land-use, forager, farmer

INTRODUCTION

The Ituri forest of northeastern Zaïre (Figure 1; approximately 6.5 million ha) is considered to have been the largest and most ecological diverse of three pleistocene refuges in the Congo basin that harbored rain forest dependent species during the last glacial interpluvial (20,000-8,000b.p.), when the area of African moist forests diminished dramatically (Hamilton, 1981; Livingstone, 1982; Moreau, 1963). Consequently, the Ituri may presently contain the most diverse and endemic assemblage of mammals of any lowland African forest (Hart, Hart, and Thomas, 1986). The Ituri, however, also contains commercially exploitable quantities of hardwoods and alluvial gold, and is a settlement frontier for peasant farmers and entrepreneurs emigrating from the densely populated Kivu region to the south of the forest (Peterson, 1990; Wilkie, 1987).

To prevent untrammelled resource exploitation and to ensure the perpetuation of the Ituri's unique biota, World Wide Fund for Nature, and Zaïre's national conservation agency (L'Institut Zaïrois pour la Conservation de la Nature) are in the process of establishing a national reserve in the region (Mankoto ma Mbalele, 1988; Sidle and Lawson, 1986).

Establishment of the Okapi Rain Forest Reserve is essential if the Ituri's unique flora and fauna are to be preserved. Conservation efforts in the Ituri are made more complex because the region is home to one of the largest remaining populations of forest hunter-gatherers in Africa (10,000+), and

*Department of Anthropology, Harvard University, Cambridge, MA 02138

supports several tribes of subsistence level slash-burn horticulturalists (50,000+). Like most rain forest populations throughout the world the inhabitants of the Ituri forest, because of their relative isolation, are only minimally assimilated into the national culture, are the last to receive social services, and are only marginally integrated into a market economy. As such they are generally unaware that their forest based resources are threatened,

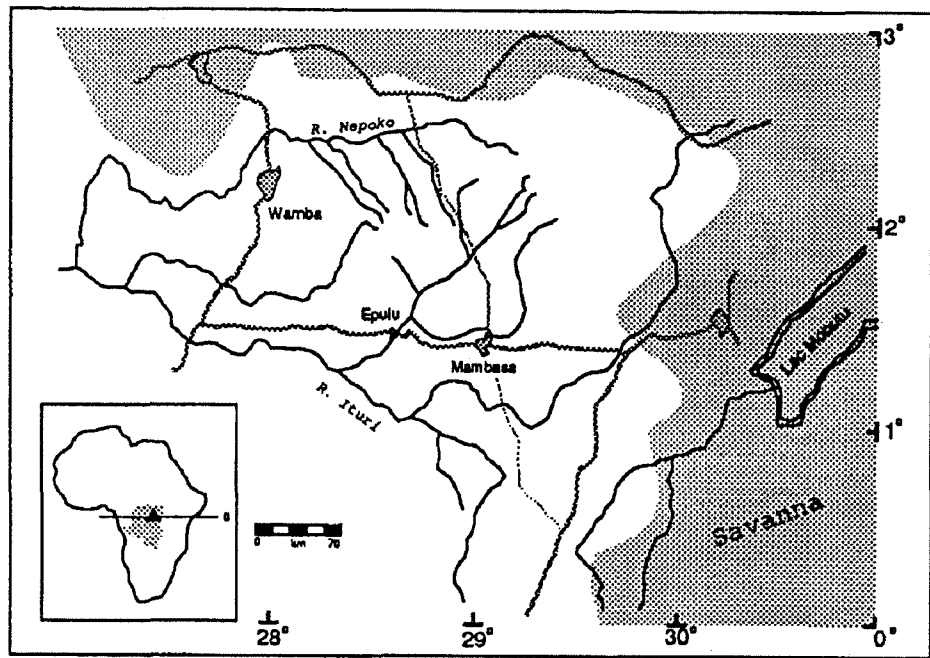


Figure 1. Ituri Rain forest of northeastern Zaire.

and without explicit land-tenure are unable to prevent more powerful commercial enterprises from taking control of their land. Thus, these populations are vulnerable to the often unilateral changes in land ownership and land-use rights that are associated with establishment of biological reserves or parks. Care must, therefore, be taken to balance the needs of biodiversity conservation with the needs and wishes of the local inhabitants.

Foragers and Farmers of the Ituri

Ancestors of the Efe and Mbuti (pygmy) foragers were probably the first inhabitants of the Ituri. Both the Efe and Mbuti still obtain the majority of their protein by hunting forest game (primarily antelope and primates) and fishing for crabs, catfish and cichlids (Bailey and DeVore, 1989). Although they gather fruits, roots and leaves that are seasonally available and widely dispersed within the forest, they now depend for 60% of their annual calories on cultivated crops obtained through trade with farmers (Bailey and Peacock, 1988). The Lese, Bira, Budu and Mamvu farmers with whom the pygmies exchange meat, honey, and field labor for cassava, plantains, maize, and rice, may have moved into the forest from the surrounding savanna once *Dioscorea* yams were domesticated (approximately 5,000 ybp) but more probably only when plantain cultivation spread from the east coast of Africa (1,000-2,000 b.p.; Vansina, 1986; Wilkie, 1988).

The farmers depend on clearing a 0.25-0.5ha section of forest on an annual basis within which to cultivate a variety of crops. Once all crops are harvested (1-2 years after planting) the field is abandoned, and lies fallow for 10-15 years before being recleared and recultivated (Miracle, 1967). Farmer settlements are thus surrounded by a characteristic mosaic of uncut forest and successional/regrowth forest patches of various ages (Wilkie and Finn, 1988). Although for a brief period in the 1950-60's farmers did grow rice, cotton and coffee for sale, collapse of the road system has seen the demise of the agricultural market and a return of the farmers to a subsistence economy (Wilkie, 1988).

Forest Resource Exploitation and Rationally Delineating Reserve Boundaries

It is clear that Ituri forest foragers and farmers depend for their daily subsistence on exploiting the very resources that WWF and IZCN hope to protect. Prohibiting access to these resources would cause extraordinary hardship to both populations, and given the size and remoteness of the region would be unimplementable in any case. Resource use by local populations necessarily has to continue. Yet if ecologically sensitive areas or unique flora and faunal species within the Ituri are to be preserved, resource exploitation will have to be managed to some degree and/or at some time in the future.

Given the need for some level of resource management, the Okapi Rain Forest Reserve will only be successful if its establishment has the active or passive support of the local forager and farmer populations. Active support will require concerted local and regional education initiatives, modelled hopefully on those already put into practice by Jefferson Hall of WWF. Environmental education should not, however, be limited to increasing awareness. It should be an empowering process by which local communities eventually are able to contribute to reserve management decision making. This will, in turn, help to foster a sense of stewardship on the part of the local community for the reserve. Local stewardship has proven successful in reducing multi-use conflicts on public lands in the U.S. and is likely to be the most effective way of keeping, for example, ivory poachers from encroaching on the reserve. Ensuring active support is however a slow process.

Tacit support, on the other hand should be almost immediate, if establishment of the reserve has minimal impact on traditional subsistence practices. Consequently, it is vital to select reserve boundaries that, in the absence of enforcement, permit continued subsistence level exploitation of forest resources by local human populations within some regions of the Ituri whilst proscribing resource exploitation in others. This ostensibly is the formula proposed for UNESCO Biosphere Reserves, where multiuse zones surround and protect core areas within which resource use is highly restricted or is prohibited altogether.

In 1986, tentative boundaries for the reserve, based primarily on ecological principles (Theberge, 1989), were proposed (Sidle and Lawson, 1986). Although an attempt was made to determine how many inhabitants of the region might be affected by establishment of the park little information on resource exploitation practices of local populations was incorporated in the reserve boundary design.

A major question remained if the reserve was to elicit only minimal conflict with local people. How do we take into account human land-use needs when determining where to establish park boundaries, or more specifically, how do we make rational decisions as to the location and width of multiuse buffer zones?

To protect the largest area of forest that will be subject to little if any resource use by human populations now or in the future, core areas of the reserve must be located as far from human settlements as possible. Thus it was essential to establish accurately the location and density of human settlements throughout the Ituri. If we are to minimize the impact of establishing the reserve on the land-use practices of the local population, the buffer zone width must be established based on the resource needs of the local foragers and farmers. To do this, the buffer zone width should be set to approximate the geographic range of resource exploitation by foragers and farmers. If these two

goals can be achieved, then to all intents and purposes establishment of the reserve will not impinge on the subsistence practices of indigenous foragers and farmers, and their exploitation of resources will rarely include core areas of the reserve.

Extent of Resource Exploitation

Studies conducted on Ituri forest farmers show that they rarely clear fields more than 3km from settlements (Wilkie and Finn, 1988; Figure 2). Similarly, the Efe and Mbuti foragers who have an intimate, long-term exchange relationship with the farmers (Grinker, 1990; Hart, 1979), restrict their hunting and gathering to within 5km of settlements for 7-10 months of the year, and only very infrequently travel as far as 15km from settlements to gather honey, catch fish, or hunt game (Wilkie, 1989a). Thus resource exploitation by human inhabitants of the Ituri is largely restricted to within 15km of farmer and forager settlements, which, as a result of their interdependent exchange relationship, are generally proximal to one another. If it were feasible to locate most human settlements within the Ituri, reserve boundaries could be selected to create the largest contiguous area that was greater than 15km from any human settlement, and thus largely free from exploitation. The reserve would therefore be composed of a core area, that would be subject to little if any exploitation by indigenous humans, surrounded by a 15km zone within which subsistence level exploitation would be allowed to continue unchanged. Basing the buffer zone width on known exploitation range should largely avoid the need to enforce resource protection policies within core areas as these regions lie beyond the radius of most indigenous peoples land-use.

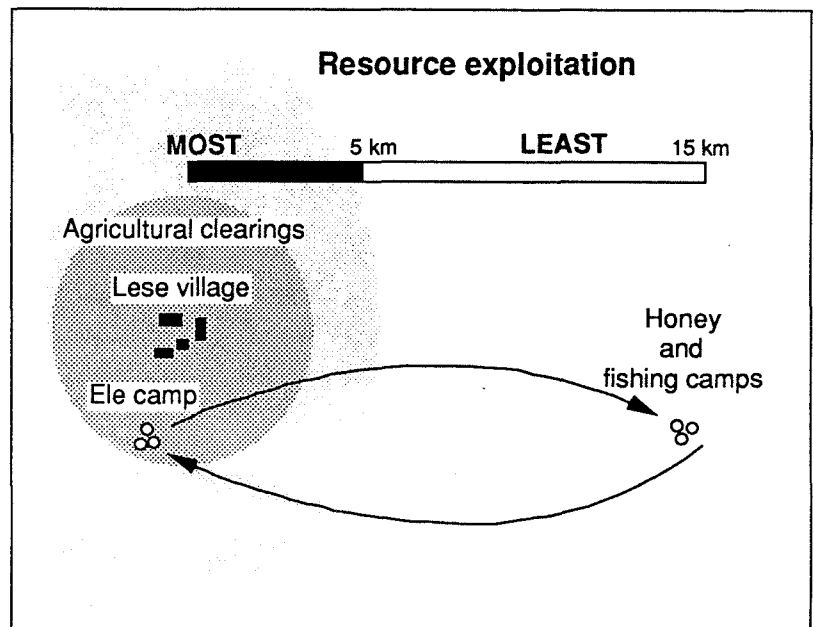


Figure 2. Range of forest exploitation by foragers and farmers.

Distribution of Human Settlements

Quickly and accurately assessing the distribution and density of human settlements over such a large and inaccessible area as the Ituri is not something that could be done on foot. Prior to the Belgian colonial period (1890's-1960), farmers and foragers settlements were small, and scattered throughout the forest near perennial rivers or streams (Grinker, 1989; Waehle, 1985). In the 1940's most foragers and farmers were forcibly resettled alongside the three dirt roads that now traverse the region (Wilkie, 1987). Since independence in 1960, and particularly during the bloody Simba rebellion (1961-65), many roadside farmers returned to their traditional villages within the forest

interior. Conversely, in the 1970's people from the forest interior moved out to the road in search of a market to trade their goods for western commodities. Given the flux of farmers and foragers to and from the road, and the absence of recent census data, it was exceedingly difficult to determine how many active settlements still existed away from the road, and where the greatest concentrations of people were located throughout the forest. Satellite image analysis was therefore the most appropriate tool to provide, quickly, a synoptic view of the Ituri that might discriminate anthropogenic landscapes from natural vegetation, and thus map human occupation of the forest.

LANDSAT Analysis

As cloud free LANDSAT TM imagery was not available for the region a scene was specifically acquired for the project in December of 1987. Although previous research indicated that the spatial and spectral resolution of TM data would be sufficient to discriminate human settlements from undisturbed vegetation, the resulting thematic map of the Ituri would only be as good as one's ability to associate spectral features within the imagery with landscape features such as fields and villages. To do this, one needs either to be able to visually relate distinctive spectral features to their corresponding landscapes, or to ascertain the exact geographic location of features both in the imagery and on the ground.

In areas with a well developed infrastructure, where landscape features are characteristically large, homogenous or recti-linear, or where ancillary data such as low altitude aerial photography or large scale maps are available, it is relatively easy to locate and identify objects on the ground that correspond to spectral classes within the imagery. Unfortunately, landscape features in tropical rain forests associated with horticulturalist settlements are characteristically small and heterogenous, and to add further confusion are surrounded by equally small and varied patches of natural vegetation. In addition, many features such as roads or rivers that might aid in geographically associating items in the imagery with those on the ground are often narrow and thus obscured by surrounding vegetation. When viewed from the air, at different scales, the Ituri appears both extraordinarily heterogenous and remarkably featureless at the same time. Identifying the pixels associated with agricultural clearings located within the 34,000km² of forest that constitutes a full TM scene was solved by using a backpack, battery powered, solar recharged GPS receiver to determine the exact location of small, often isolated landscape patches that characterize human settlements.

GPS and Ground-truth Data

The Magnavox 4400 receiver accesses a global positioning system (GPS), developed by the U.S. Government. Once all 18 NAVSTAR (Navigation System with Time and Ranging) satellites are in orbit, the system will provide accurate navigation and geographic location 24 hours a day any where on the globe (Anon, 1986). Satellite GPS will replace the older Omega, Loran-C and Transit navigation systems (Rodgers, 1983; West, 1988). NAVSTAR satellites circle the earth in 20,200km, circular orbits with a 12 hour period (Heuerman and Senus, 1983). The orbital geometry of six 55° inclined planes with 3 satellites in each plane will enable reception of direct line-of-sight navigation signals from at least 4 satellites at any point at or near the earth's surface at all times. At the time of the study six functional NAVSTAR satellites provided 10 hours of two-, and 6 hours of three-dimensional position coverage per day around the globe (Anon, 1986; Figure 3). Each satellite transmits a coarse/acquisition navigation signal that provides civilian users with geo-positioning to 15m RMS.

Simultaneous monitoring of 3 satellites gives two-dimensional (latitude and longitude) position when altitude is known using a hand-held or optional internal barometric altimeter. Four satellites provide complete 3-dimensional positioning.

A Magnavox 4400 GPS receiver, primarily designed for ship-board or land vehicle applications (Stansell, 1987), was adapted for the roadless terrain of the Ituri forest. This was accomplished by attaching the unit to a tubular aluminum backpack frame, with a two-foot detachable antenna. The system, which draws 20 watts, was powered by a 12v gel cell (DRYIT 2000, 6 amp/hr) that was recharged with an ARCO G100 (5 watts, 14.5 volts) solar panel. The complete system, frame, receiver, antenna, pre-amp, cables, two gel cells, and solar panel weighed 16kg (Figure 4).

The system was used between February and July, 1988. A four satellite constellation was available (above the horizon) 6 hours per day. Satellite rise and set times advanced approximately 4 minutes per day and varied from 1740-2340 in early February to 0720-1320 in early July. These times were obtained by querying the GPS receiver. Time from power-up to acquisition of 1 satellite varied according to the size of the canopy opening, and averaged 11.5 minutes ($n=114$, $t_{\min}=7$ minutes, $t_{\max}=79$ minutes). Positioning with 3 or 4 satellites was usually possible within 20 minutes, with stabilization of location values 4-10 minutes after onset of navigation.

A 3 or 4 satellite constellation was readily obtained in villages, fields and plantations (open area > 0.125 ha) where angle to horizon rarely exceeded 30° . Although a stable position was usually obtained within 25 minutes in open canopy areas, much longer periods were required in small

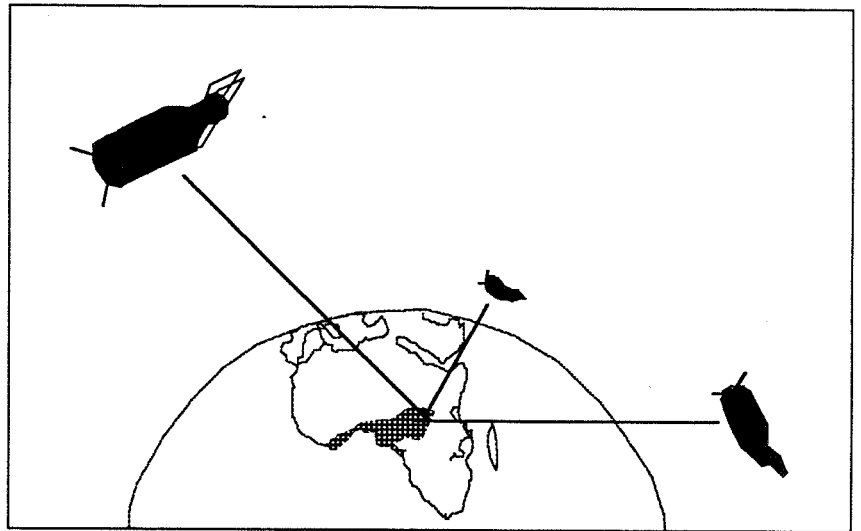


Figure 3. NAVSTAR satellite system for GPS navigation and geographic location determination.



Figure 4. A backpack, battery powered, solar recharged GPS receiver.

forest clearings where angle to horizon often exceeded 40° and canopy closure reached 30%. Forest gaps where canopy closure exceeded 30% and angle to horizon averaged more than 50° generally precluded acquisition of a 3 or 4 satellite constellation. Satellites higher than 70° above the horizon do not provide useful data for position determination.

Once a geographic position was obtained the GPS was easily transported from one site to another, allowing multiple location determination. Satellites were often lost when passing through closed vegetation zones, but were quickly reacquired when gap size expanded again in open vegetation areas. A new geographic position was generally obtained within 5 minutes of relocation in open gap areas.

With the GPS it was possible to determine accurately the location of villages, active and abandoned fields, and plantations within the forest, and to associate these features with spectral features in the imagery (Wilkie, 1990). Unfortunately, absence of sufficient ground control points negated my using much of the GPS training set data, as only a small portion of the image could be geometrically corrected to an accuracy close to that of the GPS. Regardless, it was possible to categorize horticulturalist villages, active fields and recently abandoned fields, secondary forest, open water, granite outcrops, and three general classes of mature/undisturbed forest. Although further work might improve the spectral classification, particularly in regards to mature forest classes, this first LANDSAT thematic map of the Ituri effectively differentiated human land-use from natural vegetation (Figure 5).

Using LANDSAT thematic mapper digital imagery, human settlements and population centers can easily be identified throughout the forest even though they constitute less than 3% (Table 1) of the landscape and often occur as small isolated patches. Within the region covered by the TM scene, mature forest (characterized by trees of the family *Caesalpineaceae*,) predominates, constituting some 89% of the landscape. Secondary/swamp forest constitutes a mere 6%, and fields, villages and roads less than 4%. Human settlements are primarily restricted to a 1-3km band bordering the roadways, although villages and horticultural clearings are extensive at some distance from the roads in the western sections of the Ituri.

The classified imagery revealed the distribution of the human population throughout the forest, and could distinguish active from abandoned horticultural settlements. Active agricultural settlements differ from abandoned villages because of the presence of classified pixels representative of recently slashed and burned fields, and of areas still

Table 1. Composition of landscape features with a LANDSAT TM scene of the Ituri forest.

<u>FEATURE</u>	<u>AREA (ha)</u>	<u>% COVER</u>
Mature Forest		
Northern	1,330,373	35.57
Southern	1,179,117	31.53
Western	<u>850,256</u>	<u>22.73</u>
Sub-total	3,359,747	89.43
Secondary Forest	227,920	6.09
Agriculture	60,835	1.63
Villages/Grass	62,419	1.67
Roads/Sand	2,544	0.07
Granite outcrops	2,132	0.06
Open water	11,230	0.30
Clouds/Shadow	13,405	0.36

planted with plantains, cassava, maize, and other crops. Long established horticultural settlements differ from gold-camps because although both landscapes contain recently cleared areas, only agricultural patches are surrounded with zones of regrowth vegetation associated with abandoned fields. Identification of unauthorized gold camps is important because they are responsible for introducing market hunting into the deepest reaches of the forest, and as such could threaten the sanctity of the reserve's core areas.

DISCUSSION

Using this first thematic map of the Ituri in conjunction with data on the areal extent of forager and farmer resource use, it was possible to delineate core areas and buffer zones so as to minimize present and near future land-use conflicts within the proposed Okapi Reserve (Figure 3; Wilkie, 1989b). Areas of high population density (Wamba and Mambasa) were given a wide berth to allow them to grow without encroaching on the reserve. Although an attempt was made to avoid human settlements when delineating reserve boundaries, this was not always possible. The thematic map confirmed ground based surveys (Hart, 1985; Sidle and Lawson, 1986; Hall pers. comm) indicating that topography and tree species composition was distinctively different on either side of the road that traverses the forest from east to west. In order to incorporate the distinctive southern reaches of the forest into the reserve, it was necessary to enclose the least populated strip of the Mambasa-Niania road within the reserve. This ostensibly created northern and southern core areas, connected by a few narrow corridors that cut across the multi-use buffer zone that borders the road. Although this decision clearly compromised initial goals of avoiding human settlements, its impact was minimized by integrating remote sensing and cultural information.

Creation of the Okapi Rain Forest Reserve is the first step toward ensuring the survival of the Ituri's unique flora and fauna, whilst protecting the resource exploitation rights of the indigenous human population. Future monitoring of human land-use within and bordering the reserve will be essential if the reserve is to exist in reality and not just on paper. Monitoring of forest clearing for settlements, and for agriculture will be facilitated greatly through the use of multi-temporal satellite image analyses, of which this present analysis is an integral part.

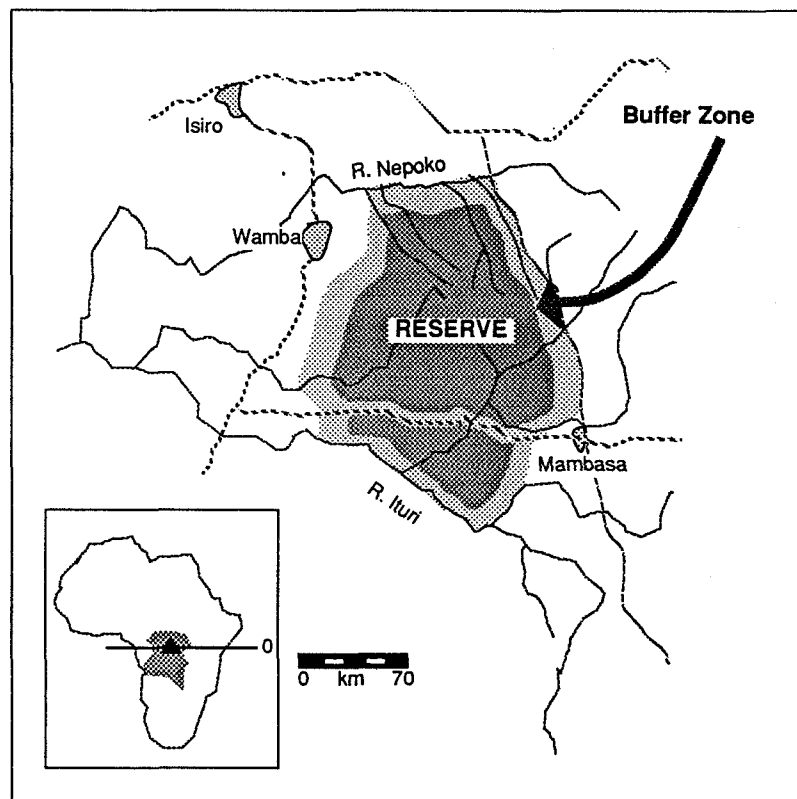


Figure 6. Core and buffer zones for Okapi Rain forest Reserve.

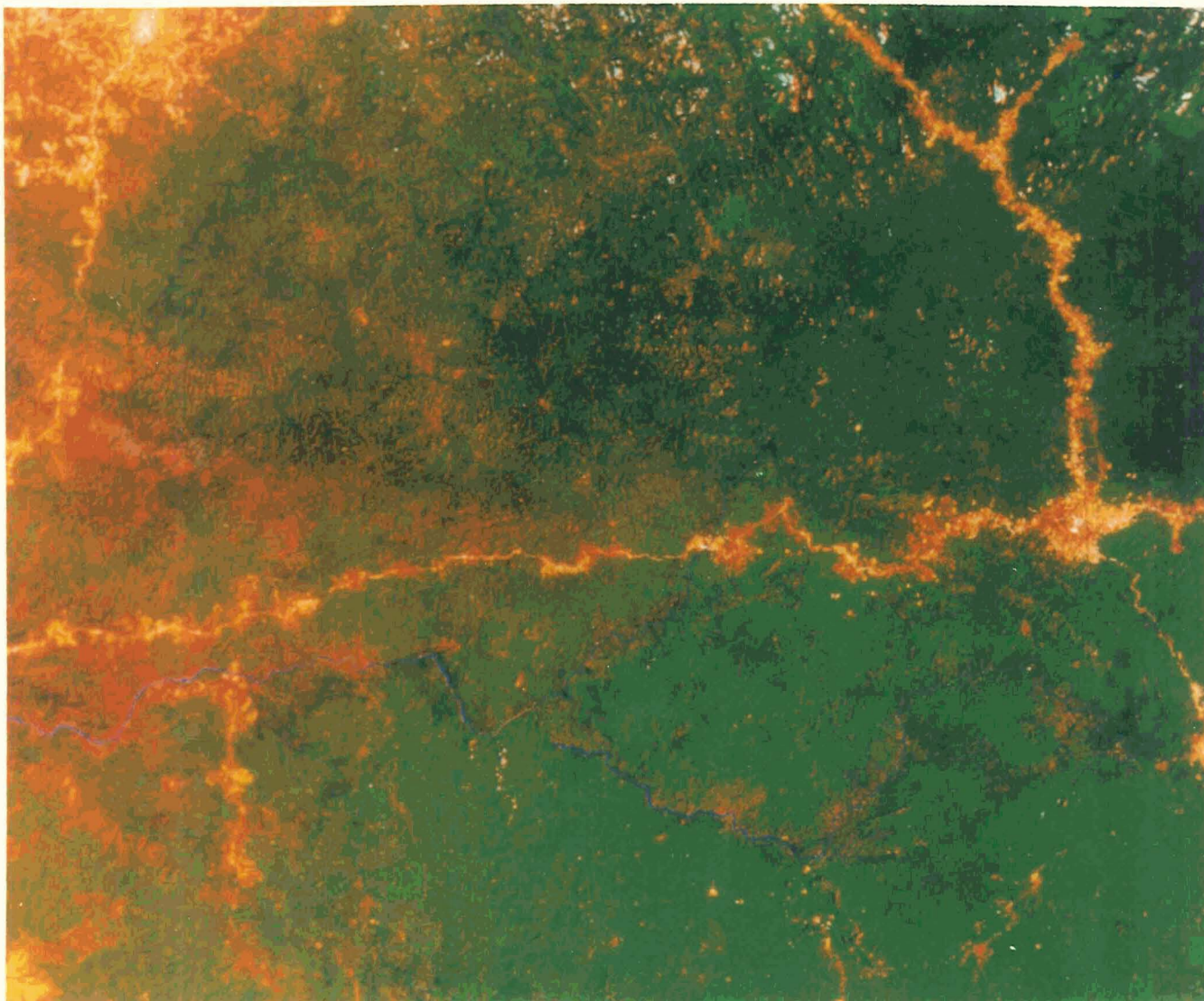


Figure 5. LANDSAT TM thematic map of the Ituri rain forest.

Future resource use within the reserve

Considering local human population's needs when establishing the reserve buffer zone will help to reduce immediate park-people conflicts. Yet, it is only one aspect of what should be a concerted effort to integrate local people into reserve planning and management. Restricting forest resource exploitation within the buffer zone to traditional subsistence uses only, imposes stasis on the local population. This leaves little room for evolutionary or revolutionary changes in subsistence practices as populations grow and develop, and will thus be extremely difficult to enforce. As changes in population size and subsistence practices are inevitable, buffer zone management plans must be formulated now that will mitigate the adverse affects of these changes well in advance of resource degradation. Alternatives to key resources, such as wildgame, need to be sought and made available. Low input agricultural techniques should be promoted that will allow for reductions in fallow period associated with increasing population density, without jeopardizing the productivity and sustainability of farming. Furthermore, if local populations are to be expected to husband the resources available to them within the buffer zone, then they must have a sense of ownership over them. This could be achieved by building on traditional, but implicit, land-tenure rights of indigenous farmers and foragers such that local communities, with the guidance of the regional government and the IZCN, can have more control over who has access to buffer zone resources, and how intensively they are to be exploited. Providing local populations with a sense of stewardship over the resources in their sections of the reserve will hopefully increase compliance in regard to resource use restrictions and will reduce or negate the need for enforcement. This in turn will minimize local resentment toward the reserve.

Involving local populations in the planning and management of the reserve will undoubtedly help in ensuring survival of the Ituri's unique biota. However, this requires that the government of Zaïre recognizes the implicit resource exploitation rights of the Ituri's human population, and in doing so also recognizes that citizens of Zaïre who do not presently inhabit the region do not share in these rights. This concept, although essential to the success of the reserve, may be the most difficult for the government of Zaïre to accept.

Gazetting of the reserve under Zaïrois law has not yet occurred (Hall, pers. comm.), although it is hoped that the reserve will formally be established sometime in 1991.

ACKNOWLEDGEMENTS

Funding for this study was provided by grants from the National Science Foundation, World Wide Fund for Nature, Gland; Wildlife Conservation International; L.S.B. Leakey Foundation; the Eppley Foundation; and the Swan Fund. Image analysis and technical assistance was provided by NASA-ERL, Stennis Space Center; and the Center for Remote Sensing and Cartography, University of Utah. Information on the progress of establishing the Okapi Rain Forest Reserve was provided by Jefferson Hall, WWF-Zaïre.

REFERENCES

- Anon, 1986. MX 4400 Global Satellite Positioning and Navigation System: Operator's Manual. Magnavox Advanced Products and Systems Company.

- Bailey, R. C., and I. DeVore, 1989. Research on the Efe and Lese populations of the Ituri forest, Zaire. *Am. J. Phys. Anthro.* 78:459-471.
- Bailey, R. C., and N. R. Peacock, 1986. Efe pygmies of northeast Zaire: subsistence strategies in the Ituri forest. In: *Uncertainty in the food supply*, de Garine, I. and G.A. Harrison (eds). Cambridge University Press.
- Grinker, R. R., 1989. Ambivalent exchanges: the Lese farmers of Central Africa and their relations with the Efe pygmies. Unpublished Ph.D. dissertation Harvard, Cambridge, pp 260.
- Grinker, R. R., 1990. Images of denigration: structuring inequality between foragers and farmers in the Ituri forest, Zaïre. *American Ethnologist* 17(1):111-130.
- Hamilton, A. C., 1981. The Quaternary history of African forests: its relevance to conservation. *Afr. J. Ecol.* 19:1-6.
- Hart, J. A., 1979. Nomadic hunters and village cultivators: A study of subsistence interdependence in the Ituri forest of Zaire. M. A. Thesis Michigan State University. East Lansing. 122pp.
- Hart, T. B., 1985. The ecology of a single-species-dominant forest and of a mixed forest in Zaire, Africa. Unpublished PhD Dissertation. pp215 Michigan State University, East Lansing MI.
- Hart, T. B., and J. A. Hart, 1985. The ecological basis of hunter gatherer subsistence in the African rain forest: the Mbuti of Eastern Zaire. *Human Ecology* 14(1):29-55.
- Hart, J. A., T. B. Hart, and S. Thoma., 1986. The Ituri forest of Zaire: primate diversity and prospects for conservation. *Primate Conservation* 7: 42-44.
- Heuerman, H. R. and W. J. Senus, 1983. Navstar global positioning system. *J. Surveying Engineering*. 109(2):73-80.
- Mankoto ma Mbalele, 1988. Un Projet d'Arrêté Départemental portant création et délimitation d'une Réserve Naturelle dénommée, Réserve de Faune à Okapi. IZCN, Kinshasa.
- Livingstone, D. A., 1982. Quaternary geography of Africa and the refuge theory. In G.T. Prance (ed.) *Biological diversification in the tropics*. Columbia University Press. pp. 527-536.
- Miracle, M. 1967. *Agriculture in the Congo Basin*. University of Wisconsin Press. Madison.
- Moreau, R. E., 1963. Vicissitudes of the African biomes in the late Pleistocene. *Proc. Zool. Soc. Lond.* 141:395-421.
- Rodgers, P. D., 1983. New positioning power for the surveyor. *J. Surveying Engineering*. 109(2):90-98.
- Sidle, J. G. and D. Lawson., 1986. Proposal for the establishment of the Okapi National Park in the

Haut-Zaïre region of the Republic of Zaïre. World Wide Fund for Nature, Gland.

- Stansell, T. A., 1987. The Magnavox civil and military line of GPS receivers - A technology and applications overview. In: Proc. Inst. Nav. Tech. Meeting, pp. 109-118.
- Theberge, J. B., 1989. Guidelines to drawing ecologically sound boundaries for national parks and nature reserves. *Environmental Management* 13(6):695-702.
- Vansina, J. 1986. Do pygmies have a history? *Sprache und Geschichte in Afrika* 7(1):431-445.
- Waehele, E., 1986. Efe (Mbuti) relations to Lese Dese villagers in the Ituri Forest, Zaïre: historical changes during the last 150 years. *Sprache und Geschichte in Afrika* 7(2):375-411.
- West, G., 1988. Radionavigation. *Popular Communications* pp. 68-69.
- Wilkie, D. S., 1987. Cultural and ecological survival in the Ituri forest: the role of accurately monitoring natural resources and agricultural land- use. *Cult. Surv. Q.* 11(2):72-74.
- Wilkie, D. S. 1988. Hunters and farmers of the African forest. In: *People of the Tropical Rain Forest*, J. S. Denslow and C. Padoch (eds.), University of California Press, pp. 111-126.
- Wilkie, D. S. 1989a. Impact of roadside agriculture on subsistence hunting in the Ituri forest of northeastern Zaire. *Am. J. Phys. Anthro.* 78(4):485-494.
- Wilkie, D. S. 1989b. Human settlement and forest composition within the proposed Okapi rain forest reserve in northeastern Zaïre. Report to World Wide Fund for Nature, Gland.
- Wilkie, D. S. 1990. GPS location data: An aid to satellite image analyses of poorly mapped regions. Technical Note. *Int. J. Remote Sensing.* 11(4):653-658
- Wilkie, D. S., and J. T. Finn, 1988. A spatial model of land use and forest regeneration in the Ituri forest of northeastern Zaire. *Ecol. Model.* 41:307-323.

PRELIMINARY GIS ANALYSIS OF THE AGRICULTURAL LANDSCAPE
OF CUYO CUYO, DEPARTMENT OF PUNO, PERU

Bruce Winterhalder*, Tom Evans**

ORIGINAL
COLOR ILLUSTRATIONS

ABSTRACT

Computerized analysis of a geographic database (GIS) for Cuyo Cuyo, (Dept. Puno, Peru) is used to correlate the agricultural production zones of two adjacent communities to altitude, slope, aspect and other geomorphological features of the high-altitude eastern escarpment landscape. The techniques exemplified will allow ecological anthropologists to analyze spatial patterns at regional scales with much greater control over the data.

INTRODUCTION

The Production, Storage and Exchange (PSE) research project was initiated with NSF support in 1984.¹ The goal was to investigate questions of agricultural ecology and economics in two communities located on the upper slopes of the eastern escarpment of the Peruvian Andes. The more specific problem was this: How do peasant agriculturalists in a marginal high-altitude environment mitigate production risk? In seeking answers to this question we identified three possible risk-reduction mechanisms available to Andean households: i) decisions to disperse fields and to inter-crop multiple cultigen varieties; ii) decisions to process and store a portion of the annual crop; and, iii) decisions to exchange labor and produce among households or communities.

Our hypotheses relied on the observation that each of these mechanisms has an efficacy which depends on cost and structural constraints (e.g., seasonal scheduling), and on the spatial and temporal nature of the risk factors. For instance, field dispersion is a viable mechanism if the factors affecting production -- frost, drought, and pests, predominantly -- are highly localized. If that is the case, dispersed fields will even out micro-climatic or pathogenic conditions (Winterhalder 1990b). Analysis of these hypotheses requires that we characterize the environment of Cuyo Cuyo in terms of its dynamic temporal properties (e.g., climate patterns and their predictability) and its spatial heterogeneity (e.g., habitat patchiness). This type of environmental characterization is part of an effort to develop more general models of processes of ecological adaptation (see Winterhalder 1980; Halstead and O'Shea 1989).

Investigation of the problem has taken the form of a multi-disciplinary project with an emphasis on quantitative methodologies.² The core of the information is three datasets gathered continuously

*Department of Anthropology & Curriculum in Ecology, University of North Carolina at Chapel Hill.

**Department of Geography, University of North Carolina at Chapel Hill.

¹BNS#8313190.

²Among the participants are a geomorphologist (D. Alexander), geographer (S. McRae), pedologist (J. Sandor) and plant ecologist (B. Bennett). The anthropologists included representatives of several subdisciplinary specialties: economic (J. Recharte), ecological (B. Winterhalder), nutritional (P. Graham), archaeological (C. Goland) and medical (A. Larme).

for a period of two years. Ten households in each of two communities were the sample. Although the communities are located nearby one another, and thus were simultaneously accessible to one research team, their territories span differing sets of ecological zones on the escarpment. Similar in socio-cultural features, the sample communities offered us a controlled ecological comparison. The data consist of i) weekly diaries of household expenditures and income; ii) a time allocation study using a spot check methodology of all individuals in the twenty families; and, iii) a field dispersion study which gathered extensive information on each of the 675 fields planted by these households over the two seasons.

In addition, we have collected ancillary data on climate in the central Andean region, primarily to document the temporal dimension of risk (Winterhalder 1990a). Archaeology (Goland 1988), geomorphology and soils have received preliminary analysis, as has vegetation ecology. We have surveyed terrace distribution, use and maintenance and have mapped these features on airphotos. One completed dissertation focused on the inter-relationships of agriculture and seasonal migration of males to mine gold (Recharte 1988, 1990). Dissertations in progress will examine field dispersion as a risk-reduction mechanism (Goland), healing and the relationships of work to health (Larme), and household nutrition and food management (Graham). Most of these datasets have focused on the same sample of 20 households and they overlap in time. This has generated a multi-disciplinary record of information unique in being derived from the same, long-term sample.

GIS AND SPATIAL ANALYSIS IN ANDEAN ECOLOGY

By virtue of rugged topography and steep altitudinal gradients, the Andes present sharp contrasts of environmental conditions within short distances (Winterhalder and Thomas 1982; Gomez Molina and Little 1981). Strong vertical zonation of environment, complicated by the effects of local topography, slope and exposure, has figured prominently in andean life. Whatever their social organization, from the very earliest prehistoric period the peoples in the Andes have attempted to mobilize this micro-environmental diversity to insure an adequate and reliable livelihood (Murra 1984). Transhumant hunter-gatherers (Lynch 1973) moved up and down the slopes following seasonal resource opportunities. With the domestication of plants and animals and the evolution of kingdom and state level polities, similar integration of diverse zones was accomplished through various forms of centrally organized colonization, exchange and trade (Browman 1981, 1984). In the contemporary period, markets partially have supplanted zonal integration achieved earlier by household and community-level exchange. The rich archaeological, ethnohistorical and ethnographic documentation available in the Andes have made the region a focus for studies of history and ecology, and their relationships (Orlove and Guillet 1985).

Drawing on ethnohistoric study of the Lupaqa, a small 16th century kingdom located on the north end of Lake Titicaca, the anthropologist John Murra (1968, 1981) has characterized this organizational form by an *archipelago*, or *verticality*, model (Brush 1976; Orlove 1977). Typically, andean polities had their main populations and administrative locus in the high altitude plateaus, but they developed forms of economic organization that insured access to dissimilar production zones extending down the vertical gradients of both the western and eastern slopes of the mountains. In some cases, these were isolated "islands" of production, not geographically contiguous with the centralized territory.

Based on this brief introduction, we can identify three considerations that have encouraged attention to the spatial dimension in the PSE analyses: i) we are attempting to conceptualize ecological adaptation at a generalized level of temporal and spatial processes; ii) the Andean environment forces attention to the micro-ecological scale of unique landscape elements; and iii) we know in general

terms that andean economies from the earliest to the present have succeeded through their ability to integrate this environmental diversity. Understanding those economies in ecological terms requires methodologies that can facilitate complex spatial analyses.

GOALS OF PAPER

This paper will present results of our use of ArcInfo,³ a geographic information system (GIS), to assist in this research. We focus primarily on the three-dimensional TIN (Triangulated Irregular Network) module. We will illustrate our uses of GIS, discuss problems we have encountered and describe analytical protocols to circumvent them.

Project history dictates that the results are preliminary. Although the PSE group anticipated using GIS and remote sensing as early as 1982, in the early phases of the project we were able only to digitize the relevant portions of 9 (1:25,000) topographic maps.⁴ This year Winterhalder and Evans were able to resume the GIS portions of the analysis.⁵ The work has proceeded more slowly than we anticipated, due to a series of technical difficulties. Indeed it will be a subtext of this presentation that whatever the original research questions one should approach GIS in an exploratory and skeptical frame of mind. However attractive for analysis and display of large, spatially-referenced datasets, at this point in its development the methodology itself can become a significant part of the research effort.

MAP COVERAGES AND ANALYSES

The bulk of our coverages (or map layers) derive directly or indirectly from portions of the nine 1:25,000 (7.5' UTM Projection) topographic maps that cover some part of our study area.⁶ The nine

³ArcInfo is a vector-based GIS, produced by Environmental Systems Research Institute, Redlands, CA.

⁴This work was done by our collaborating geographer (Stephen McRae), then at UC Riverside.

⁵Supported by an NSF, Anthropology Program, Quantitative Methodology Training Grant (BNS# 8901823).

⁶They are:

	<u>ScaleName</u>	<u>Index</u>
1:25,000	Ananea	30X-1-SE
1:25,000	Ancolala	29Y-III-SO
1:25,000	Cuyo Cuyo	29X-II-SE
1:25,000	Huarachani	30X-I-SO
1:25,000	Janccocala	30X-I-NE
1:25,000	La Rinconada	30Y-IV-NO
1:25,000	Punalaquequi	29X-II-SO
1:25,000	Sorraccocha	30X-I-NO
1:25,000	--	30Y-IV-SO
1:100,000	Limbani	29X
1:100,000	Putina	30X
1:100,000	La Rinconada	30Y

These maps were copied onto mylar and digitized from that more stable medium. Portions of the 1:100,000 map series were redrawn at a larger scale (Kargl projection unit) to produce contour lines for small areas missing from the 1:25,000 maps. Corner tics were derived from the US Army technical Manual (TM - 5-241-11) and interpolated from the nearest labeled UTM grid intersection.

quadrangles total 1,675 km². From this, we have boxed off and digitized a study region of 1,046.7 km² (62.5% of the original quadrangles). This study region surrounds the District of Cuyo Cuyo which along with the communities of Huancasayani and Nacoreque makes up a core research sample of 430.25 km² (Figure 1). PSE has focused intensive analysis on two of the peasant communities located

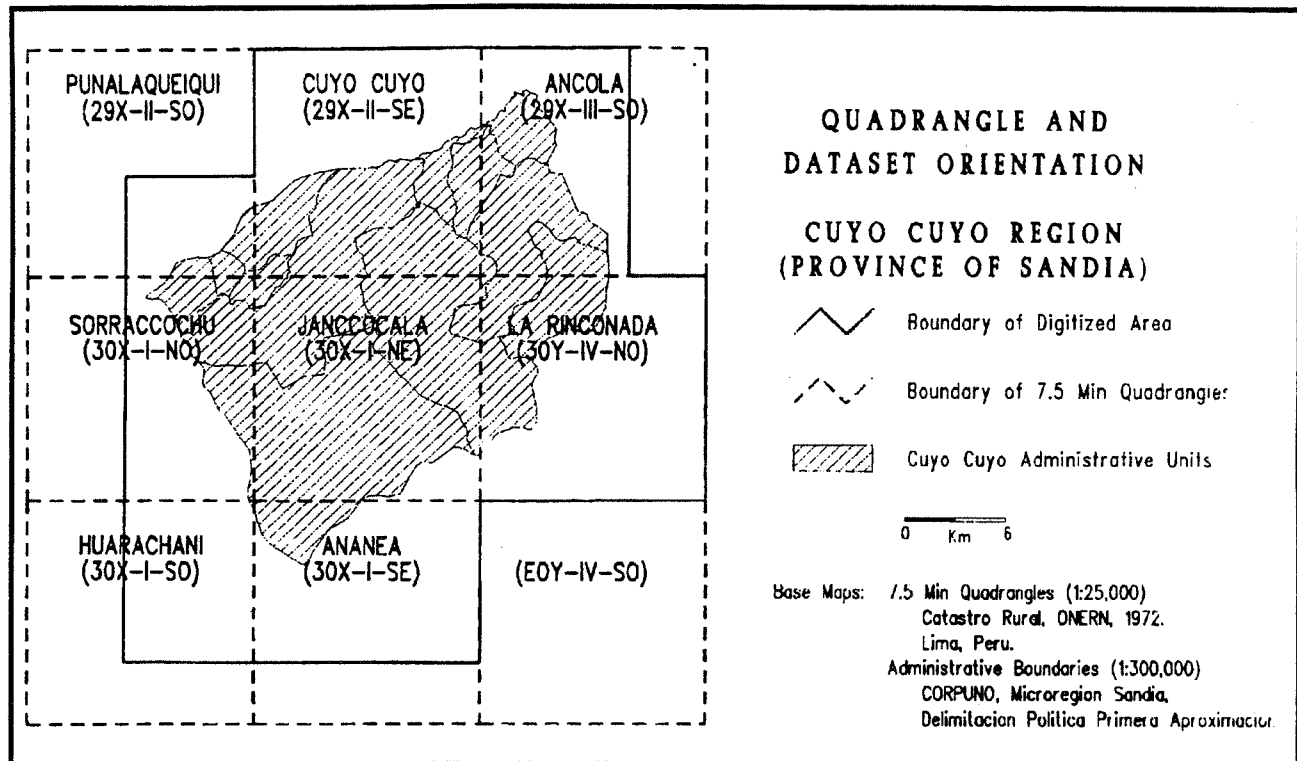


Figure 1. Quadrangle and Data Set Orientation.

within the District, Puna Ayllu (79.16 km²) and Ura Ayllu (21.09 km²).⁷

A description of the main, single-theme coverages is given in Table 1. Existing coverages include those derived directly from quadrangle maps (Adminplus/Adminall, Circulation, Contours/100msamp, & Vegezones), those based on field mapping by PSE personnel (Archeo, Sites), and those derived indirectly from contour lines using the TIN module (Aspectsmp, Distin08T, & Slopesmp). In the near future we plan to add coverages from field work (Fldsmp, PlantCom, & GeomphSmp), and from analysis of a Landsat TM image (LndSatSmp).

⁷Digitizing was done with a Calcomp 9100 digitizing tablet, using the ArcInfo Automated Digitizing System. Subsequent editing was done in ArcEdit using a Tektronix 4109 Color terminal. This was a lengthy and occasionally frustrating, labor-intensive process performed mostly by work-study students at UC-Riverside. The digitizing of the 100m contours, which define elevation provinces and from which slope and aspect are derived, required most of the effort. Administrative boundaries, transportation networks and general land use or cover features required less time. Translating the quadrangle maps to a computer format required reconciliation of numerous small errors and inconsistencies in the horizontal positioning of elevation information (for instance, contours occasionally did not meet precisely when we attempted to edge-match the original quadrangles to produce a composite map).

Table 1. PSE-GIS coverages (or map layers) and their source(s).¹

Coverage Name for:		Source ²	Description
Region	Sample		
EXISTING:			
Adminplus	Adminall	Base maps	Political boundaries of the District, comunidades & anexos
Archeo	--	Field Records	Archaeological Survey area (see Goland 1988)
--	Aspectsmp	TIN/contours	Aspect, in 45 deg increments (N, NW, W, SW, S, SE, E, NE)
Circulation	--	Base maps	Roads and trails
Contours	100msamp	Base maps	100 meter contour intervals
--	Distin08T	TIN/contours	Tin-derived coverage with aspect, slope and surface area, by district
Sites	--	Field Records	Position and area of located archaeological sites (Goland 1988)
--	Slopesmp	TIN/contours	Slope, in graduated increments
Vegezones	Vgznsmp	Base maps	Altitude-delimited vegetation zones identified by Camino et al., 1981)
Rivers	Riversmp	Base maps	Rivers & major streams
Water	Watersmp	Base maps	Lakes
PLANNED:			
--	Fldsmp	Field Records	All plots from the field dispersion study
--	PlantCom	Field Records	Distribution of plant communities.
--	Geomphsmp	Field Records	Map of geomorphological features
--	LndSatSmp	EOSAT	Digital (TM) satellite image

¹Not listed are individual quadrangle boundaries, various combinations of administrative boundaries, or composite maps made by unioning together these individual coverages.

²*Base maps* = derived directly from existing quadrangles; *Field records* = derived from maps drawn by project members on base maps, supplemented with 1:40,000 and 1: 10,000 airphotos; *TIN/contours* = TIN-produced coverages, deriving ultimately from base map contour lines.

Landscape

We will now turn to some analytical issues using the database and graphics potential of GIS. For geographical orientation, the contour coverage of the study region is shown in Fig. 2. Moving from southwest to northeast, one crosses the high plains of the Ananea plateau toward the peaks of the cordillera. This area is typical of the more elevated portions of the andean Altiplano; the drainage is toward Lake Titicaca and the interior of the basin. The mountains, here the Carabaya and Apolobamba ranges, dissect the coverage on a southeast to northwest axis. The glaciated peaks of these mountains reach above 5300m and the passes through them are around 4400m. Their northeast flanks form the headwaters of drainages that begin the precipitous descent of the eastern escarpment toward the Amazon basin. The Awi Awi, Cuyo Cuyo and Huancasayani rivers converge near the northern margin of the coverage⁸ to form the Rio Sandia, which becomes the Rio Wari Wari, then Inambari and eventually Madre de Dios. The lowest point on the coverage occurs near its northeaster corner at 2600m. Figures 4 and 5 present a three-dimensional view of the central portion of this landscape that we are studying intensively (corresponding to the cross-hatched, "Administrative Units" portion of Figure 1).

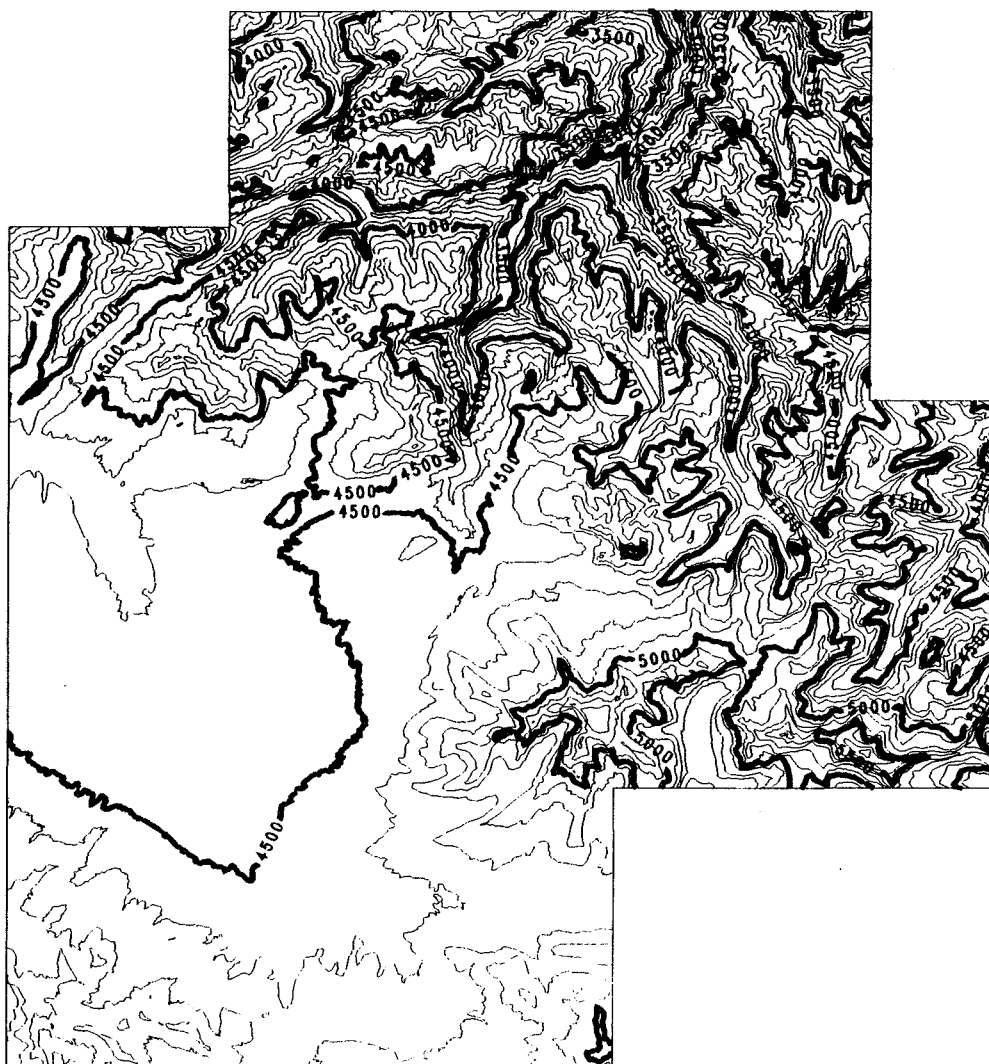
Tightly compressed production zones characterize the steep andean slopes. Extended use of this "vertical" landscape is typical of household and community economic organization. Even a simple description of the resource potential of community lands requires a quantitative assessment of their distribution by altitude. A cross-tabulation of elevation by community with cell entries representing area provides this analysis (Table 2; Graph 1). The lower of our two study communities, Ura Ayllu (elevation, 3400m; total area, 21.09 km sq; population, 856) has lands extending from 2600m to 4300m [range, 1800m]. This represents a fairly even distribution of 130 to 180 hectares of land at each of the 100m elevation intervals between 3300m and 4200m. The larger community of Puna Ayllu (elevation, 3800m; area, 79.16 km sq; population, 1776), has lands extending from 3400m to 4800m [range, 1500m]. However, 89% of its territory is at elevations of 4100m or higher, above the limits of horticultural production. By comparison, 80% of Ura Ayllu's territory is below 4100 m in elevation. In the research sample as a whole, over 82% of the 430.25 km² lies at or above 4100m.

There are 208 lakes in the study area, all located between 4000 and 4700m, with nearly 90% of the water surface at 4300m. Lakes cover 20% of the map area at this altitude (Table 3). Most of these lakes are very small (135 are less than one hectare in extent); the largest ones (see Figure 4) are 4.41 km² and 2.43 km².

Archaeological Survey



Working in such a rugged and physiologically difficult terrain, our archaeological team was especially concerned to know the relative extent and representativeness by altitude of the area that they were able to survey. Table 4 shows the altitude distribution of the survey area relative to the total area of the research sample. The archaeologists examined slightly more than 10% (44.18 km sq) of the study area (430.25 km sq). Lands above 4700m (= 15,416 feet) were not sampled, those between 4400 and 4600 m were sampled but not in proportion to their extent, and from 2800 to 4300m, an even 20 to 30% of each 100 meter interval was surveyed.

⁸These drain the three headwaters in the coverage, from northwest to southeast, respectively (see also Figure 3).



CUYO CUYO REGION

100 METER CONTOUR INTERVALS

 500 Meter Interval
 100 Meter Interval


 0 Km 4

Base Maps: 7.5 Min Quadrangles (1:25,000)
 Catastro Rural, ONERN, 1972
 Lima, Peru.
 30 Min Quadrangles (1:100,000)
 Carta Nacional, Instituto
 Geografico Militar, Lima, Peru.

Figure 2. Cuyo Cuyo Region: 100m Contour Intervals.

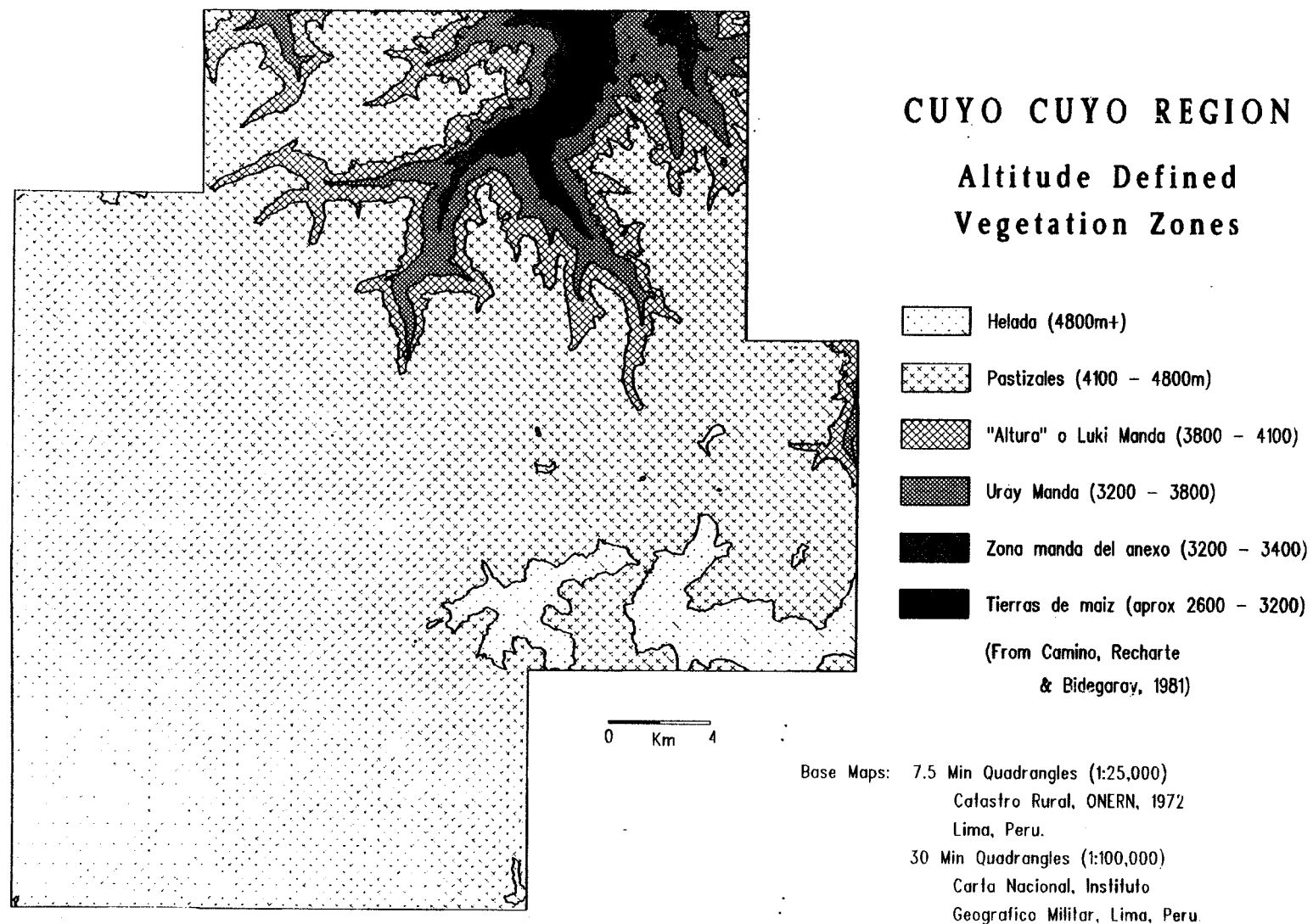


Figure 3. Cuyo Cuyo Region: Altitude-Defined Vegetation Zones.

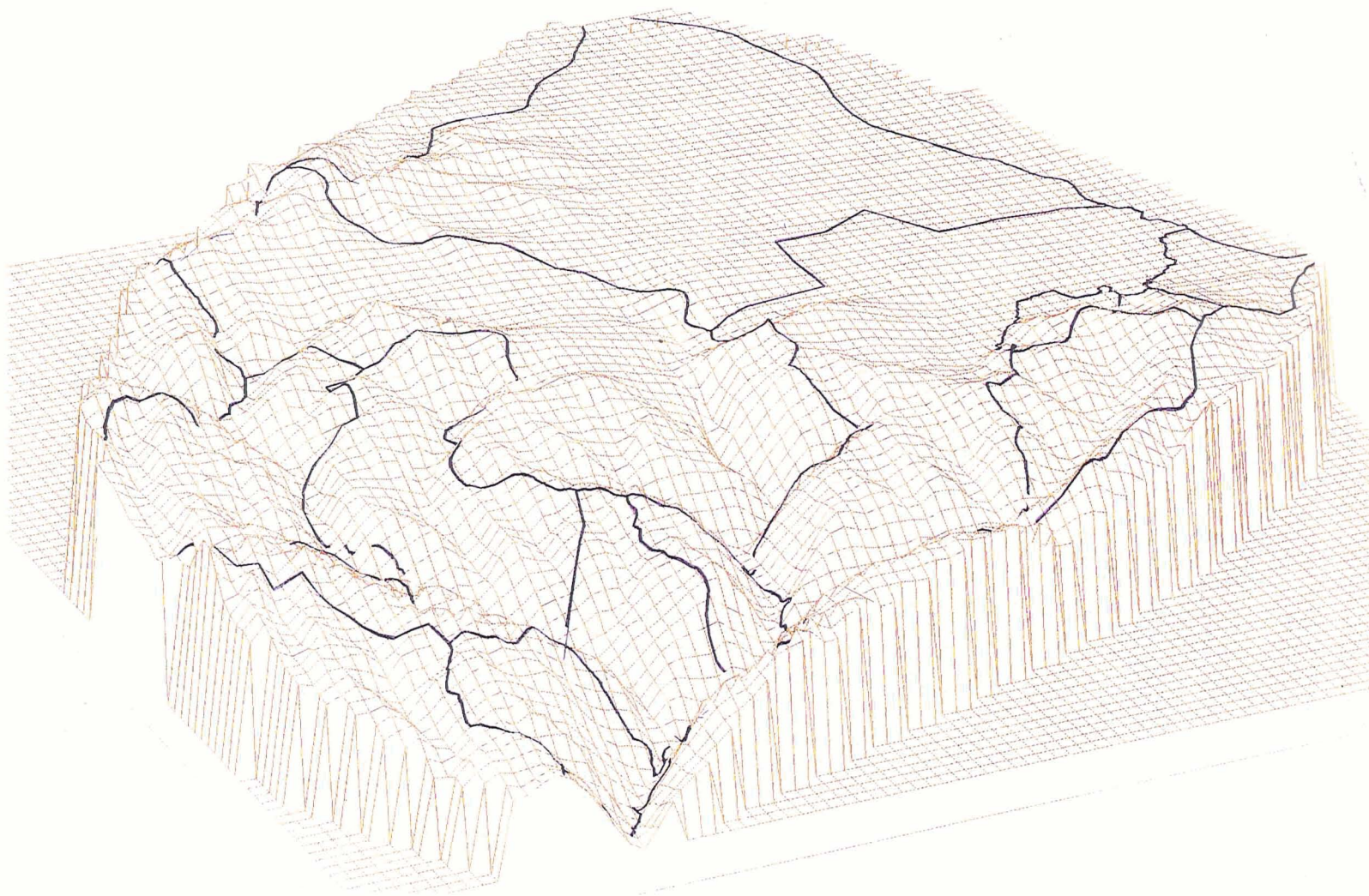


Figure 4. Three-Dimensional View of the Study Sample, from Northeast, with Administrative Boundaries



Figure 5. Three-Dimensional View of Study Sample, from Southwest, with Lakes.

Table 2. Elevation by Area for Study Communities.

Elev m	Other		Puna Ayllu		Ura Ayllu		Total	
	km sq	Col%	km sq	Col%	km sq	Col%	km sq	Col%
5300	0.07	0					0.07	0
5200	0.43	0					0.43	0
5100	1.20	0					1.20	0
5000	2.89	1					2.89	1
4900	6.44	2	0.01	0			6.45	1
4800	14.15	4	0.51	1			14.66	3
4700	24.10	7	3.14	4			27.24	6
4600	36.75	11	5.94	8			42.69	10
4500	70.86	21	13.74	17	0.01	0	84.61	20
4400	74.64	23	25.22	32	0.10	0	99.96	23
4300	23.24	7	16.01	20	0.70	3	39.95	9
4200	16.29	5	3.43	4	1.66	8	21.38	5
4100	13.96	4	2.52	3	1.83	9	18.31	4
4000	11.04	3	2.11	3	1.92	9	15.07	4
3900	8.06	2	1.81	2	1.41	7	11.28	3
3800	6.73	2	1.73	2	1.39	7	9.85	2
3700	5.19	2	1.29	2	1.37	6	7.85	2
3600	4.03	1	0.94	1	1.38	7	6.35	1
3500	3.29	1	0.61	1	1.31	6	5.21	1
3400	2.59	1	0.15	0	1.75	8	4.49	1
3300	1.81	1			1.69	8	3.50	1
3200	1.17	0			0.96	5	2.13	0
3100	0.60	0			1.03	5	1.63	0
3000	0.31	0			0.86	4	1.17	0
2900	0.15	0			0.71	3	0.86	0
2800	0.04	0			0.60	3	0.64	0
2700	0.00				0.30	1	0.30	0
2600	0.00				0.11	1	0.11	0
TOTAL	330.03	100	79.16	100	21.09	100	430.28	100

Table 3. Elevation by Area for Lakes.

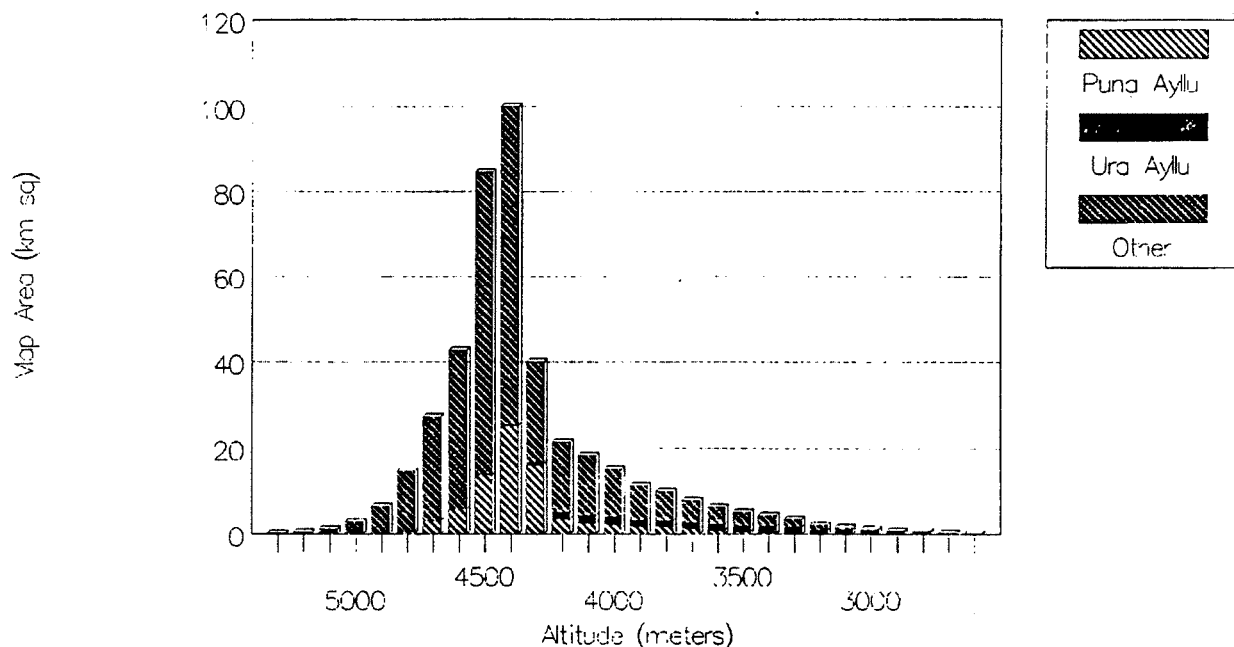
Elev m	Terrestrial		Lakes		Total	
	km sq	Col%	km sq	Col%	km sq	Col%
5300	0.07	0			0.07	0
5200	0.43	0			0.43	0
5100	1.20	0			1.20	0
5000	2.89	1			2.89	1
4900	6.45	2			6.45	1
4800	14.65	3	0.01	0	14.66	3
4700	27.08	6	0.16	2	27.24	6
4600	42.61	10	0.08	1	42.69	10
4500	84.23	20	0.38	4	84.61	20
4400	99.74	24	0.22	2	99.96	23
4300	32.02	8	7.93	89	39.95	9
4200	21.30	5	0.08	1	21.38	5
4100	18.27	4	0.04	0	18.31	4
4000	15.02	4	0.04	0	15.06	4
3900	11.27	3			11.27	3
3800	9.84	2			9.84	2
3700	7.84	2			7.84	2
3600	6.34	2			6.34	1
3500	5.21	1			5.21	1
3400	4.49	1			4.49	1
3300	3.50	1			3.50	1
3200	2.13	1			2.13	0
3100	1.63	0			1.63	0
3000	1.18	0			1.18	0
2900	0.86	0			0.86	0
2800	0.63	0			0.63	0
2700	0.30	0			0.30	0
2600	0.11	0			0.11	0
TOTAL	421.29	100	8.94	100	430.23	100

Table 4. Elevation by Area for Archaeological Survey

Elev m	Non-Survey		Survey		Total	
	km sq	Col%	km sq	Col%	km sq	Col%
5300	0.07	0			0.07	0
5200	0.43	0			0.43	0
5100	1.20	0			1.20	0
5000	2.89	1			2.89	1
4900	6.45	2			6.45	1
4800	14.66	4			14.66	3
4700	27.24	7			27.24	6
4600	42.66	11	0.03	0	42.69	10
4500	83.03	22	1.59	4	84.62	20
4400	94.23	24	5.73	13	99.96	23
4300	33.46	9	6.49	15	39.95	9
4200	15.03	4	6.35	14	21.38	5
4100	13.20	3	5.11	12	18.31	4
4000	11.07	3	3.99	9	15.06	4
3900	8.38	2	2.89	7	11.27	3
3800	7.79	2	2.05	5	9.84	2
3700	5.80	2	2.04	5	7.84	2
3600	4.46	1	1.89	4	6.35	1
3500	3.60	1	1.61	4	5.21	1
3400	3.00	1	1.49	3	4.49	1
3300	2.32	1	1.18	3	3.50	1
3200	1.56	0	0.57	1	2.13	0
3100	1.21	0	0.42	1	1.63	0
3000	0.83	0	0.35	1	1.18	0
2900	0.61	0	0.25	1	0.86	0
2800	0.48	0	0.15	0	0.63	0
2700	0.29	0	0.00		0.29	0
2600	0.11	0	0.00		0.11	0
TOTAL	386.06	100	44.18	100	430.24	100

Distribution of Land by Altitude

Ura Ayllu, Puna Ayllu and Other



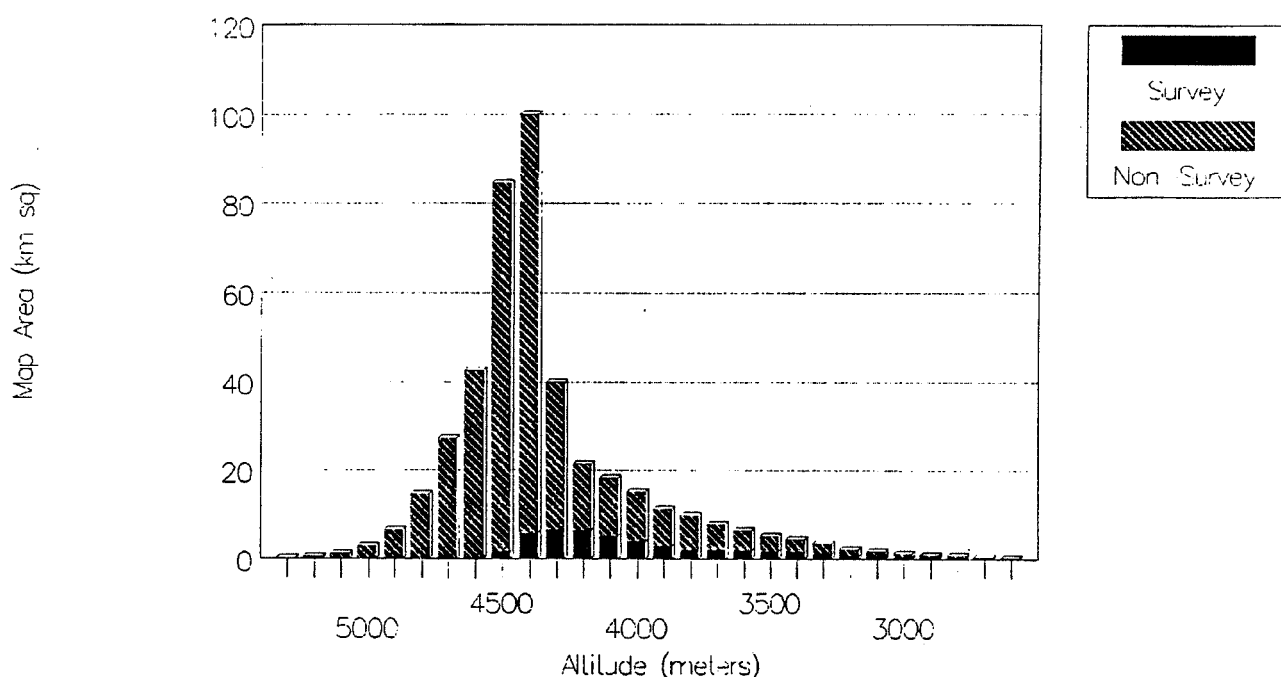
Graph 1. Distribution of Land by Altitude

A total of eight sites were located (Goland 1988). They fall between 3400 m and 4400 m, but the majority of them and the larger part of the area covered are in the upper end of this range, at or above 4100m (areas given in hectares):

Site name:	<u>CC-2</u>	<u>CC-3</u>	<u>CC-4</u>	<u>CC-5</u>	<u>CC-6</u>	<u>CC-7</u>	<u>CC-8</u>	<u>CC-9</u>	<u>TOTAL</u>
Elev (m)									
4400	2.11				0.05		4.66		6.81
4300		0.02			0.53	5.04			5.58
4200		5.76		0.35		4.30			10.42
4100				1.71					1.71
4000									
3900									
3800			1.35						1.35
3700			0.79						0.79
3600									
3500							1.82		1.82
3400							0.01		0.01
Total	2.11	5.78	2.14	2.06	0.58	9.34	4.66	1.83	28.49

Distribution of Arch Survey by Altitude

Extended District of Cuyo Cuyo



Graph 2. Distribution of Archeological Survey by Altitude

Land Use Zones

In 1981 Camino et al. surveyed the Cuyo Cuyo region and identified key agricultural zones. Because their zonal boundaries were defined by elevation a GIS coverage of these features is a reclassification by altitude. By combining (unioning) the vegetation zone coverage with that for political boundaries we can calculate the distribution of these zones by community (Table 5). The results confirm and refine our impression of basic ecological differences between the two study communities. Puna Ayllu has 89% of its territory in the high altitude pasture zones, another 7% in the production zone suitable only for frost-hardy bitter potatoes, and only 4% of its area (2.99 km sq) in the main tuber and habas zone of the valley. Puna Ayllu has no territory in the lower tuber or maize zones. In contrast, the production zones of Ura Ayllu are more diverse and evenly represented. Ura Ayllu has 20% of its territory in the pasture region, 22%, 28% and 13% in the upper, middle and lower tuber production zones, respectively, and an additional 17% located at altitudes suitable for cultivation of maize.

Table 5. Agricultural Zone by Area for Study Communities.

Zone*	Other		Puna Ayllu		Ura Ayllu		Total	
	km sq	Col%	km sq	Col%	km sq	Col%	km sq	Col%
H	4.59	1	.00	0	.00	0	4.59	1
A	280.40	85	70.52	89	4.29	20	355.21	83
B	25.82	8	5.65	7	4.71	22	36.18	8
C	15.09	5	2.99	0	5.80	28	23.88	6
D	2.99	1	0.01	0	2.65	13	5.65	1
E	1.10	0	.00	0	3.61	17	4.71	1
TOTAL	329.99	100	79.17	100	21.06	100	430.22	100

*H = (Helada), glaciers & snowcaps, 4800m+; A = (Pastizales), pasture lands, 4100-4800m; B = (Luki Manda, Altura), bitter potato zone, 3800m-4100m; C = (Uray Manda), tuber production zone, 3400-3800m; D = (Zona Manda del Anexo), lower tuber production zone, 3200-3400m; E = (Tierra de maíz), maize production zone, 2600m-3200m.

TIN ANALYSES⁹

We have reproduced as Appendix I the TIN protocol used to create the 3d views and analyses which

⁹The TIN module of ArcInfo produces a three dimensional representation of a map which has at least one spatial attribute (x,y coordinates) and an associated vertical scale (z). In our case these are Cartesian points taken from contours lines, and their associated elevations, respectively. The irregular topography of a landscape is approximated by fitting it with a surface of contiguous triangles. Each triangle is a polygon, defined by its corner points, perimeter, area, elevation, slope angle and slope aspect. This method of surface representation is economic for a digital computer to store and analyze, and it allows one to produce profiles and three-dimensional views, along with network and various kinds of three-dimensional analyses.

In practice the TIN module requires a large number of steps, each one subject to experimentation and the occasional pitfall (Appendix I). One must start with a larger coverage than ultimately is desired (as margins shrink during processing), manually add to the contour map points representing peaks, swales, saddles and other topographic inflection points, convert the coverage to a TIN, transform the TIN to a lattice, apply various filters to smooth and augment different aspects of relief, apply an algorithm that uses generally known topographic relationships to further enhance the geographical realism of the surface, then reconvert the lattice to a TIN (for 3d views, which can be "draped" with other coverages), convert the TIN to a polygon coverage, clip the polygon coverage to the desired boundary, and dissolve on the continuous slope and aspect variables to create coverages which represent those features categorically. If analyses are desired, the Info files of these coverages must be exported from ArcInfo. They then can be reformatted and imported into a database or statistical package such as SAS. This can be a difficult and time-consuming procedure.

are presented in this section. It describes the sequence of steps, the commands used and the parameters which we adopted, sometimes after considerable experimentation. It also provides some analytical guidelines, draws attention to unanticipated difficulties and describes our solutions.

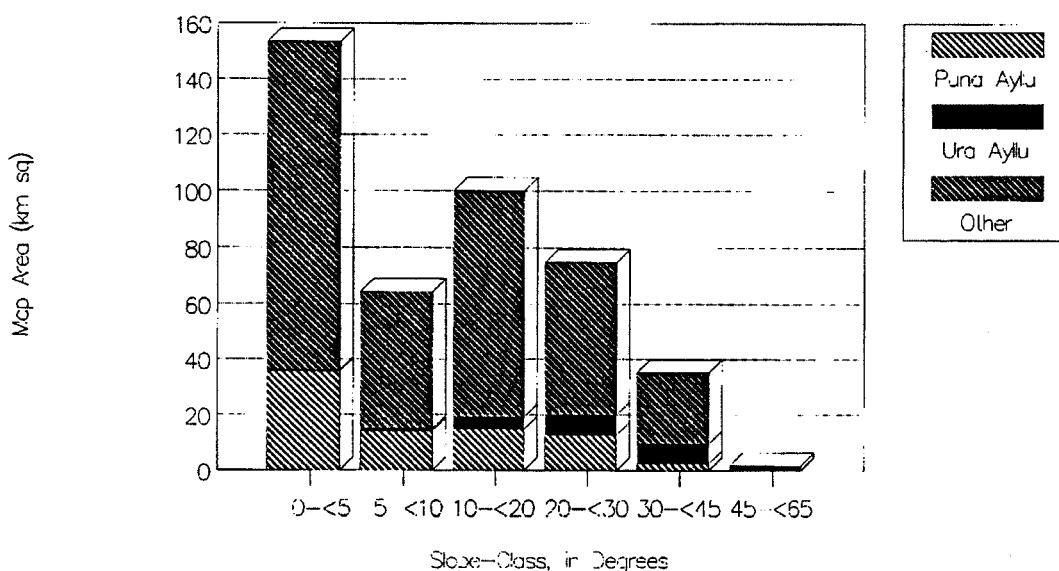
Slope, Aspect and Surface Area

The TIN module of ArcInfo allows one to create coverages representing slope angle, slope aspect and elevation. These can be unioned with other coverages to produce more specific, cross-tabular analyses. In Table 6 (Graph 3) we show the distribution of slope classes by community. Note that the lands of

Table 6. Slope-Class by Area for Study Communities.

Slope (deg)	Other		Puna Ayllu		Ura Ayllu		Total	
	km sq	Col %	km sq	Col %	km sq	Col %	km sq	Col %
0=<5	117.30	36	35.66	45	0.36	02	153.32	36
5=<10	49.35	15	14.22	18	0.76	04	64.33	15
10=<20	80.97	25	14.74	18	4.37	22	100.08	23
20=<30	54.85	17	12.71	16	7.32	37	74.88	17
30=<45	25.61	8	2.41	3	7.11	36	35.13	8
45=<65	1.54	0	0.07	0	0.10	0	1.71	0
TOTAL	329.62	100	79.81	100	20.02	100	429.45	100

Distribution of SlopeClass by Community
Extended District of Cuyo Cuyo



Graph 3. Distribution of Slope-Class by Community

Puna Ayllu are distributed among the lower slope angles (45% less than 5 degrees; 81 percent less than 20 degrees). This is consistent with their location on a high plain with heavily weathered hills. By contrast, the lands of Ura Ayllu are concentrated at the steeper angles (73% at an angle of 20 degrees or more). They occupy the steep canyon sides and narrow valley bottoms of the heavily dissected headwaters of the eastern escarpment.

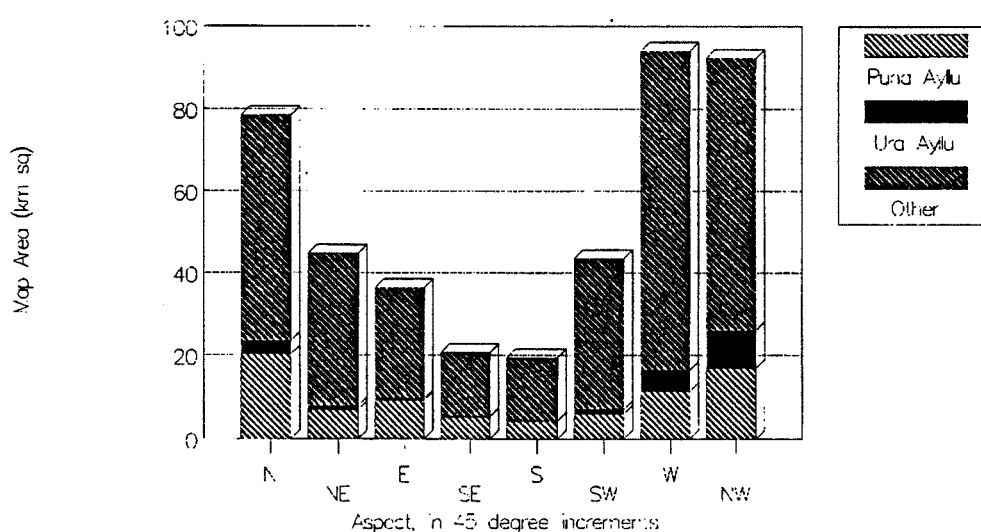
Table 7 (Graph 4) depicts aspect for the study sample (in 45 degree increments). Puna Ayllu lands

Table 7. Aspect-Class by Area for Study Communities.

Aspect*	Other		Puna Ayllu		Ura Ayllu		Total	
	km sq	Col%	km sq	Col%	km sq	Col%	km sq	Col%
N	55.01	17	20.20	25	3.25	16	78.46	18
NE	36.89	11	6.96	9	0.92	5	44.77	10
E	26.75	8	9.14	11	0.42	2	36.31	8
SE	15.19	5	5.20	7	0.18	1	20.57	5
S	15.05	5	4.29	5	0.05	0	19.39	5
SW	36.53	11	5.89	7	1.10	6	43.52	10
W	77.75	24	11.30	14	4.99	25	94.04	22
NW	66.38	20	16.83	21	9.08	45	92.29	21
	329.55	100	79.81	100	19.99	100	429.35	100

**In 45 degree increments.*

Distribution of Aspect by Community Extended District of Cuyo Cuyo



Graph 4. Distribution of aspect by Community

are distributed across slopes facing in all compass directions, with slight biases to the W, NW and N. Nearly all (86%) of the land of Ura Ayllu faces these three directions, that is toward the northwest quadrant. Although Ura Ayllu lands are steep (Table 6), their aspect is advantageous. In this southern hemisphere location, crops facing toward the north receive extra solar radiation. And those on slopes with a northwestern orientation do not suffer the shock of strong early morning sunlight on frosted plants (as would occur if they faced toward the NE quadrant).

Anyone who has spent much time in mountain environments knows that steep-slope habitats defy two-dimensional maps. This has a physiological element that can be felt in the calves and lungs. It has a perceptual element, as it takes great skill to create and manipulate a complex three-dimensional image using a flat topographic map. Of greater importance, it has an analytical element. Among the more important measures of human-environment relations are those routinely calculated with reference to area (population density, crop production statistics, etc.). Yet it virtually never is specified if the denominator value used in these calculations is the map area (the area a slope projects onto a horizontal plane) or the *actual surface area on the ground*. Our facile reference to the "areas" of Puna and Ura Ayllu in Tables 1 through 5 (actually map rather than surface area) is an example. The possible degree of error produced by this oversight is easily calculated for a plane of uniform angle:

Degree slope	Percent increase of surface relative to map area
10	1.5%
20	6.4%
30	15.5%
40	30.5%
50	55.6%
60	100.0%

Uncertainty of this magnitude surely will complicate precise analysis of relationships among slope, population and agricultural productivity in mountain environments.

On the andean escarpment it is unexceptional to find fields on steep slopes, whether they are terraced or not. Calculations based on map and surface areas will produce significant differences. In Table 8 we describe the relationship between surface area and horizontal or map area for the Cuyo Cuyo study communities. The results are based on our TIN analysis (see Appendix I). The ratio ranges from a low of 1.01:1 for Churura, a small annexo on the high plain above Cuyo Cuyo, to 1.13:1 for the study community of Ura Ayllu. To illustrate the potential biases of ignoring the surface/map area distinction, note that potato production on the average Ura Ayllu slope (8535 kg/ha,

Table 8. Relationship of Map to Surface Area, Cuyo Cuyo Districts.

Community or Annex	Map km sq	Surface km sq	Ratio Surface/Map
Calpapata	28.89	32.38	1.12:1
Churura	117.06	118.46	1.01:1
Cojene-Rotojoni	85.55	91.65	1.07:1
Huacchani	10.46	10.64	1.02:1
Huancasayani	44.78	48.93	1.09:1
Huanomoco	18.09	19.20	1.06:1
Nacoreque	13.72	15.09	1.10:1
Puna Ayllu	79.33	81.74	1.03:1
Pacneria	3.88	4.04	1.04:1
Soracchocha	6.63	6.88	1.04:1
Ura Ayllu	19.25	21.70	1.13:1
TOTAL	427.64	450.71	1.05:1

surface area) would jump to 9,621 kg/ha, if calculated by map area.¹⁰ The Ura Ayllu population density of 41.3 individuals/km sq (map area) would fall to 36.6 individuals/km sq if calculated by surface area.

In summary, Puna Ayllu lands are characterized by low-slope and diverse aspects. They are predominantly high altitude plains located above the margin of agriculture, with limited extensions into the upper, frost-hardy potato zones. The community of Ura Ayllu is much smaller and steeper, with territory spread fairly evenly from the highest tuber producing zones to altitudes low enough to permit maize cultivation. Nearly all of the Puna Ayllu land faces onto the northwestern quadrant.

PLANNED ANALYSES

As demonstrated, GIS can be used to generate the base-line data necessary to analyze the relationships between peasant ecology and economics. Our planned studies build on this base to address more directly questions of production and risk.

Field Distribution

A key component of our research effort is analysis of field distribution as a potential risk-reduction mechanism. We have adopted a micro-economic model developed by the economic historian Donald McCloskey and originally applied in studies of field dispersion in medieval England (McCloskey 1976). At its simplest, the model assesses the trade-off between a benefit (reduced harvest variability and thus diminished likelihood of an unwelcome shortfall, as greater numbers of dispersed and independently varying fields are added to the crop inventory), and a cost (the diminished average net productivity of each field as travel time and transportation costs grow). Because both the benefits and costs are a function of the number of fields, a simple optimization model allows one to examine this relationship quantitatively (Winterhalder 1990b).

However, the analytical demands of the model are enormous. It is something entirely different to handle the spatial dimension, multiple variables and sample sized necessary to make a careful quantitative analysis of this question. McCloskey used impressive historical skills and analytical ingenuity in deriving parameter estimates from the documentary sources available to him. In the Andean case, we have been able to measure many of the relevant variables directly. Over the two years of our sample, we have gathered approximately 80 pieces of information on each of 675 fields (488 unique plots, allowing for those planted in both of the consecutive years of our sample). These fields are small (average size is 240m²). Families disperse their agricultural efforts into an average of 17 plots/year. Using surface area, production ranges from 8535 kg/ha for potatoes to 1162 kg/ha for habas. Other tuber crops are intermediate in productivity: oca = 8269 kg/ha; illaco = 5836 kg/ha; isano = 6892 kg/ha.

We currently are digitizing these field locations. Making them a coverage in our GIS will give us analytical control over relationships between crop distribution and production, and geographical factors such as elevation, slope and aspect. It gives us visual tools for analyzing the movement of fields and cultigens among valley-wide units of the sectorial fallow rotation. And, it gives us efficac-

¹⁰This calculation is hypothetical, as much of Ura Ayllu's potato production occurs on the more gentle incline of terrace surfaces.

ious means of calculating travel and transportation costs (using the NETWORK module of ArcInfo) important in our model. These studies are pending, but we are optimistic about their potential.

Terrace Distribution, Use and Abandonment

The stone-faced terraces that dominate the agricultural landscape of Cuyo Cuyo apparently are the product of a massive, technologically proficient and highly organized human effort. Our archaeological survey suggests that they are anywhere from 900 to 1500 years old (Goland 1988). Examination of partial cross-sections produced by slides reveals they have a standardized and complex wall form and internal structure. Ground survey of maintained and collapsed areas suggests that they once were even more extensive than they are today.

Terrace use, maintenance, and reclamation have become practical issues throughout the Andes, but little is known about their distribution, functions or productivity. There may be a million hectares of terraces in Peru, 75% of which currently are abandoned. This is a sizeable figure when compared to the 2.6 million hectares of land under cultivation in this land-scarce country (Denevan 1987). As part of the PSE project, one of us (BW) has mapped the distribution of maintained and abandoned terraces in the Cuyo Cuyo area on small-scale (1:10,000) air photos. We expect to digitize this information as a GIS coverage and then to use the spatial sampling capacities of ArcInfo to determine if terrace location is systematically affected by altitude, slope, exposure, distance from settlement, or other factors. It is easy to imagine hypotheses about these relationships, but without the systematic and quantitative capacities of GIS, it will be impossible to rigorously test them.

Micro-Climate and Remote Sensing

Two more envisioned projects will conclude this prospectus of GIS applications in Cuyo Cuyo. First, our analyses are demonstrating high correlations between some measures of climate (e.g., monthly rainfall predictability) and geographic variables like altitude (see Winterhalder 1990a). We hope eventually to use GIS to translate these relationships into climatic maps with much greater accuracy and at a much smaller scale than presently is possible in a heterogeneous region like the Andes. Prediction of the effects of climate change on agricultural production and peasant livelihood will depend on such capacities. Second, we anticipate a much more sophisticated analysis of vegetation cover and land use as we are able to incorporate landsat TM data into our coverages. We are just beginning to work with a landsat scene of Cuyo Cuyo from March 1987, toward the end of the growing season and coincident with the second year of our detailed field studies.

CONCLUSIONS

It has been the genius of Andean peoples to adapt an inhospitable environment to human purposes. Pre-Columbian agriculturalists pushed the upper limits of crop production and pastoralism with andean domesticates to above 4000m. They used the cold to advantage by freeze-drying tubers for storage as a hedge against risk. They developed complex political and administrative systems in order to integrate and pool the resources of diverse, complementary micro-environmental zones (Murra 1984). Our attempts to understand and in some cases recover that knowledge, to preserve it, and to apply it for the benefit of current and future andean peoples will depend on our achieving similar levels of environmental sophistication. GIS and remote sensing will be useful tools in that process.

ACKNOWLEDGEMENTS and EQUIPMENT

This work has been supported by NSF grant (BNS# 8901823; Bruce Winterhalder, PI) and by the Remote Sensing/GIS Laboratory at UNC -- CH (Stephen Walsh, Director). The more-or-less permanent residents of the Lab (Andrew Weatherington, Dan Brown, Ling Bian, Maggie Kelly, and Matthew Owen) have been generous with equipment, materials, time, advice and encouragement. Ernie Patterson (Curriculum in Ecology) and Martin Feinstein (Academic Computing Services, DEC/VAX Services) have provided essential technical assistance.

The Remote Sensing/GIS Laboratory at UNC Chapel Hill is equipped with a Digital Microvax II with five Tektronix 4209 graphics terminals. The primary software packages on the Microvax are ERDAS, a raster-based image processing package, and ARC/INFO, a vector-based GIS package. The lab also has a Sun workstation for ERDAS image processing with a separate ArcInfo site license. Processing in this lab is aided by the campus-wide VAX 6330, which also has an ARC/INFO site license, and a Compaq work station with ERDAS and an ArcInfo live-link connection. Communication is possible between all of these processors through the campus Ethernet and inter-lab Telnet connections. Hardcopy devices include a Tektronix 4693 four color printer and a Calcomp 1025 for large-format plots.

BIBLIOGRAPHY

Browman, David L. 1981. New light on Andean Tiwanaku. American Scientist 69: 408-419.

Browman, David L. 1984. Tiwanaku: Development of interzonal trade and economic expansion in the Altiplano. In Social and Economic Organization in the Prehispanic Andes. D.L. Browman, Richard L. Burger, and Mario A. Rivera, eds. Pp. 117-142. Oxford, UK: BAR International Series 194.

Brush, Stephen B. 1976. Man's use of an Andean ecosystem. Human Ecology 4: 147-166.

Camino, Alejandro, Jorge Recharte, and Pedro Bidegaray. 1981. Flexibilidad calendárica en la agricultura tradicional de las Vertientes Orientales del los Andes. In La Tecnología en el Mundo Andino. Tomo I. Subsistencia y Mensuración. H. Lechtman, and A.M. Soldi, eds. Pp. 169-194. México: Universidad Nacional Autónoma de México.

Denevan, William M. 1987. Terrace abandonment in the Colca Valley, Peru. In Pre-Hispanic Agricultural Fields in the Andean Region. Part 1. William M. Denevan, K Mathewson, and G. Knapp, eds. Pp. 1-43. Oxford, UK: BAR International Series 359(i).

Goland, Carol. 1988. Prehispanic Occupation of the Eastern Andean Escarpment. PSE Working Paper No. 1. Department of Anthropology, UNC -- Chapel Hill.

Gomez Molina, Eduardo, and Adrienne V. Little. 1981. Geoecology of the Andes: The natural science basis for research and planning. Mountain Research and Development 1: 115-144.

Halstead, Paul, and John O'Shea. 1989. Introduction: Cultural responses to risk and uncertainty. In Bad Year Economics: Cultural Responses to Risk and Uncertainty. Paul Halstead and John O'Shea, eds. Pp. 1-7. Cambridge: Cambridge University Press.

Lynch, Thomas F. 1973. Harvest timing, transhumance, and the process of domestication. American Anthropologist 75: 1254-1259.

McCloskey, Donald N. 1976. English open fields as behavior towards risk. *In* Research in Economic History 1. P. Uselding, ed. Pp. 124-170. Greenwich, CT: JAI Press.

Murra, John V. 1968. An Aymara Kingdom in 1567. Ethnohistory 15: 115-151.

Murra, John V. 1981 [1972]. The 'vertical control' of a maximum of ecologic tiers in the economies of Andean societies. *In* Visita of the province of León de Huánuco. Vol 2 [Ortiz de Zuñiga]. Escobar, D. Chavin and Gabriel Escobar M., eds. [Reprint; English translation 1981].

Murra, John V. 1984. Andean societies. Annual Review of Anthropology 13: 119-141.

Orlove, Benjamin. 1977. Integration through production: The use of zonation in Espinar. American Ethnologist 4: 84-101.

Orlove, Benjamin, and David W. Guillet. 1985. Theoretical and methodological considerations on the study of mountain peoples: Reflections on the idea of subsistence type and the role of history in human ecology. Mountain Research and Development 5: 3-18.

Recharte, Jorge. 1988. Qori Llank'ay: Gold Mining Technology in a Community Mine, Northern Region of Puno, Peru. PSE Working Paper No. 2. Department of Anthropology, UNC -- Chapel Hill.

Recharte, Jorge. 1990. Value and Economic Culture among the Peasant Gold Miners of the Cuyo Cuyo District (Northern Puno, Peru). PSE Working Paper No. 3. Department of Anthropology, UNC -- Chapel Hill.

Winterhalder, Bruce. 1980. Environmental analysis in human evolution and adaptation research. Human Ecology 8: 135-170.

Winterhalder, Bruce. 1990a. Rainfall and temperature patterning and predictability with respect to water management in the central Andes of southern Peru. *In* Irrigation at High Altitudes: The Social Organization of Water Control Systems in the Andes. W. Mitchell and D. Guillet, eds. (in press).

Winterhalder, Bruce. 1990b. Open field, common pot: Harvest variability and risk avoidance in agricultural and foraging societies. *In* Risk and Uncertainty in Tribal and Peasant Societies. E. Cashdan, ed. Pp. 67-87. Boulder, CO: Westview Press.

Winterhalder, Bruce., and R. Brooke Thomas. 1982. Geoecología de la región montañosa del sur del Perú: Una perspectiva de adaptación humana. Occasional Paper No. 38. Institute of Arctic and Alpine Research. U of Colorado, Boulder.

APPENDIX I

Steps in a TIN Analysis

The following protocol describes the specific steps that we have used to create the PSE TIN analyses. By overlooking some of the details specific to our coverage, it also can be read as a general guide to procedures, problems and solutions.

1. CLIP a wide-margin, *line* coverage from the contours coverage, using adminwmar as the clip boundary.

[This creates a line coverage of the 100m contour intervals as the basis for the TIN. It is clipped with boundaries (adminwmar) slightly larger than and encompassing the desired slope/aspect analysis area (equivalent to adminall coverage), to allow for margin shrinkage during filtering and for later removal of anomalous edge effects].

2. Add points ($n = 41$) for peaks, swales and for any boundary points that would be concave on the basis of end points of adjacent contour lines. TIN procedures work best on coverages with a convex hull. This creates coverage DISTIN00, which is the basis of all subsequent TIN manipulations.

[The elevations of the marginal points were interpolated from the quadrangle maps, using a temporary union of contours with adminplusb (a union of adminwmar and the map boundaries) to aid in correctly positioning the elevation estimates. Note that the La Rinconada quadrangle was not available so none of its peaks were added as points to the DISTIN00].

3. Arctin DISTIN00 to create DISTIN01. Command sequence: ARCTIN DISTIN00 DISTIN01 ALL ELEV 50 50.

[This creates a coverage with 23,728 nodes; 50 hull nodes; 47404 triangles, and minimum and maximum elevations of 2600m and 5376m respectively].

4. Tinlattice DISTIN01 to create DISTIN02. Command sequence: TINLATTICE DISTIN01 DISTIN02 SMOOTH.

[Select 296 x-axis and 315 y-axis points, to yield a $d_x = 100\text{m}$ and a $d_y = 100\text{m}$. This gives a lattice of 93,536 points].

5. Filter DISTIN02 to create DISTIN03. Command sequence: FILTER DISTIN02.LAT DISTIN03 LOW 1.

[Low filtering smooths jagged edges introduced by earlier TIN procedures].

6. Vip DISTIN03 to create DISTIN04. Command sequence: VIP DISTIN03.LAT DISTIN04 45.

[This will recreate the lattice using an algorithm that selects the topographically most significant points. The 45% selection finds 43,929 points (of an estimated 42,091), using the DISTIN03 lattice (which itself has 93,536 points)].

7. Arcin DISTIN04 to create DISTIN05. Command sequence: ARCTIN DISTIN04 DISTIN05 POINT SPOT 125 125.

[This creates a TIN coverage with 11570 nodes, 73 hull nodes and 23065 triangles; minimum z is 2614m; maximum z is 5367m].

8. Tinarc DISTIN05 to create DISTIN06. Command sequence: TINARC DISTIN05 DISTIN06 POLY DEGREE #.

[This creates a polygon coverage which has slope (in degrees) and aspect variables (variables are called "items" in ArcInfo). There are 23,066 polygons, i.e., the 23065 of the TIN coverage plus the global polygon created by the perimeter. The area is 626.98 km sq].

9. Clip DISTIN06 with ADMINALL to create DISTIN07. Command sequence: CLIP DISTIN06 ADMINALL DISTIN07 POLY 100.

[This clips the slope/aspect polygon coverage to the margins of the political units that comprise the sample for analysis. In effect, at this point we excise the marginal regions introduced by using adminwmar in the original clip (see step 1). DISTIN07 contains 15,669 polygons and has an area of 430.67 km sq. It contains variables for slope ("DEGREE_SLOPE"), aspect ("ASPECT") and surface area ("SAREA"). In anticipation of later procedures, the item names SLOPE-CLASS and ASPECT-CLASS should be added to this coverage].

10a. Union DISTIN07 with ADMINALL to create DISTIN08. Command sequence: UNION DISTIN07 ADMINALL DISTIN08 100 JOIN.

[This joins the administrative boundaries with the slope/aspect polygon coverage, so that later analyses can be done by community. DISTIN08 has 15369 polygons, an area of 429.26 km sq and, in addition to the variables mentioned immediately above, now has an item for DISTRICT. Use repeat DROPITEMS to get rid of unnecessary variables ADMINALL-ID, ADMINALL#, DISTIN07-ID, and DISTIN07#. DISTIN08 will be used mainly to calculate the **surface area** of the landscape available in different administrative units within the District].

10b. Export INFO portion of DISTIN08, for file transfer and analysis. Command sequence: EXPORT INFO DISTIN08.PAT DISTSFAR NONE.

[This will export the info (database) portion of the DISTIN08 coverage into an uncompressed, ascii file with the name DISTSFAR.E00. After editing to remove header and footer materials, and to insure column alignment and excision of unwanted variables, it is translated to a SAS data file. Note that procedures for transfer, editing and translation will depend on local hardware and software options].

11a. Create lookup tables, to dissolve the DEGREE_SLOPE and ASPECT variables into categories of SLOPE-CLASS and ASPECT-CLASS.

[The look-up tables are constructed according to the intervals and item conventions given in the tables immediately below. Note that for the **slope** classification the intervals are not uniform in width, but increase as slope grows steeper in the following sequence: 5, 5, 10, 10, 15, 20, and 25 degrees.

For **aspect** the 360 degrees of the circle have been divided into eight equal quadrants centered on the 0, 45, 90, 135, etc., degree axes].

SLOPETBLA

Slope Interval (degrees)		Slope-Class	
	Degree_Slope		Symbol
0 <= x < 5	5.0	1	0
5 <= x < 10	10.0	2	1
10 <= x < 20	20.0	3	2
20 <= x < 30	30.0	4	3
30 <= x < 45	45.0	5	5
45 <= x < 65	65.0	6	7
65 <= x < 90	90.0	7	9

ASPECTBL

Aspect description		Aspect-class	
	Aspect		Symbol
North	22.5	1	0
Northeast	67.5	2	1
East	112.5	3	2
Southeast	157.5	4	3
South	202.5	5	4
Southwest	247.5	6	5
West	292.5	7	6
Northwest	337.5	8	7
North	360.0	1	0

11b. Within INFO, select **DISTIN07** and use the relate command to create an item with the proper degree-slope and aspect value for each record. This is done with commands as follows:

```
SELECT DISTIN07.PAT
RELATE SLOPETBLA BY DEGREE_SLOPE WITH TABLE NUMERIC
CALCULATE SLOPE-CLASS = $1SLOPE-CLASS
```

```
SELECT DISTIN07.PAT
RELATE ASPECTBL BY ASPECT WITH TABLE NUMERIC
CALCULATE ASPECT-CLASS = $1ASPECT-CLASS
```

11c. Use the dissolve command to create a slope class coverage and an aspect class coverage. The command sequence is as follows:

DISSOLVE DISTIN07 SLOPECOV SLOPE-CLASS POLY

DISSOLVE DISTIN07 ASPECTCOV ASPECT-CLASS POLY

[Before running these procedures, assign the global polygon an arbitrary SLOPE-CLASS and ASPECT-CLASS value (e.g., 15) that is not represented among the values for these variables in the slope or aspect lookup tables. The world polygon must have a dissolve item value different from any of the values for the interior polygons. This circumvents a software bug in the dissolve procedure, in which the global polygon is confused with other polygons with which it shares a border].

12a. Union slopecov, aspectcov, adminall, and 100msamp to create a file named U03. Command sequences:

```
UNION SLOPECOV ASPECTCOV U01 50 JOIN
UNION U01 ADMINALL U02 50 JOIN
UNION U02 100MSAMP U03 50 JOIN
CLEAN U03
```

12b. Export the Info (database) portion of U03 for analysis with SAS (see 10b).

[Prior to export, use INFO commands (Reselect, List) to check all items (variables) for values that are missing, out of range, or illogical in context (e.g., larger values for the surface than map (the horizontal projection) area of a sloped polygon). In our experience, one can count on a small number of such anomalies, especially along the margins of a TIN-generated coverage. Some of these can be fixed with INFO procedures (such as eliminate, to take care of sliver polygons) or by use of arcedit to locate and manually supply or correct the values].

SOME ADDITIONAL TIN PROBLEMS, WITH SOLUTIONS

Problem:When using processes that require a fuzzy tolerance, the default values often yields strange results. The anomalous coverages have arcs that are clipped together at odd points and often the shape and area of the polygons are changed in inappropriate ways. These results are particularly problematic for closely spaced contour lines (steep slopes).

SOLUTION: To preserve the integrity of the original coverage, we have started routinely using a very small value (e.g., 10m for the UTM coordinate system) for the fuzzy tolerance option.

Problem:When the TIN coverage is clipped with an attribute coverage, illogical values appear for area and surface area (e.g., area > surface area, negative values, values out of range). Apparently this is due to a difference in the number of digits for the x and y coordinates (UTM system). Because y coordinates had one more digit, precision errors occur in the calculation of area.

SOLUTION: To resolve this problem, the coverages were transformed into a new coordinate system, with one digit removed from the y coordinate. The steps are as follows:

1. Copy <old coverage> <new coverage>
2. Within INFO, select the <new coverage> .TIC file
3. CALCULATE YTIC = YTIC - 8000000
4. Within ARC: Transform <old coverage> <new coverage>. Do this to both the TIN coverage and the clip coverage, then subsequent clips yield logical values.

Problem: When the TIN coverage was unioned with one of the attribute coverages, surface area values no longer are correct relative to area. Whenever an attribute coverage overlaps (e.g., bisects) a TIN polygon, the union procedure creates two new polygons. The area variable in each polygon produced by the split is corrected, but the surface area variable of the original TIN polygon is carried over into both of the new, derived polygons [i.e., The union process makes the proportionate adjustments to area, but treats surface area value as it would any other item in the attribute table: it assigns it unchanged to both of the new polygons].

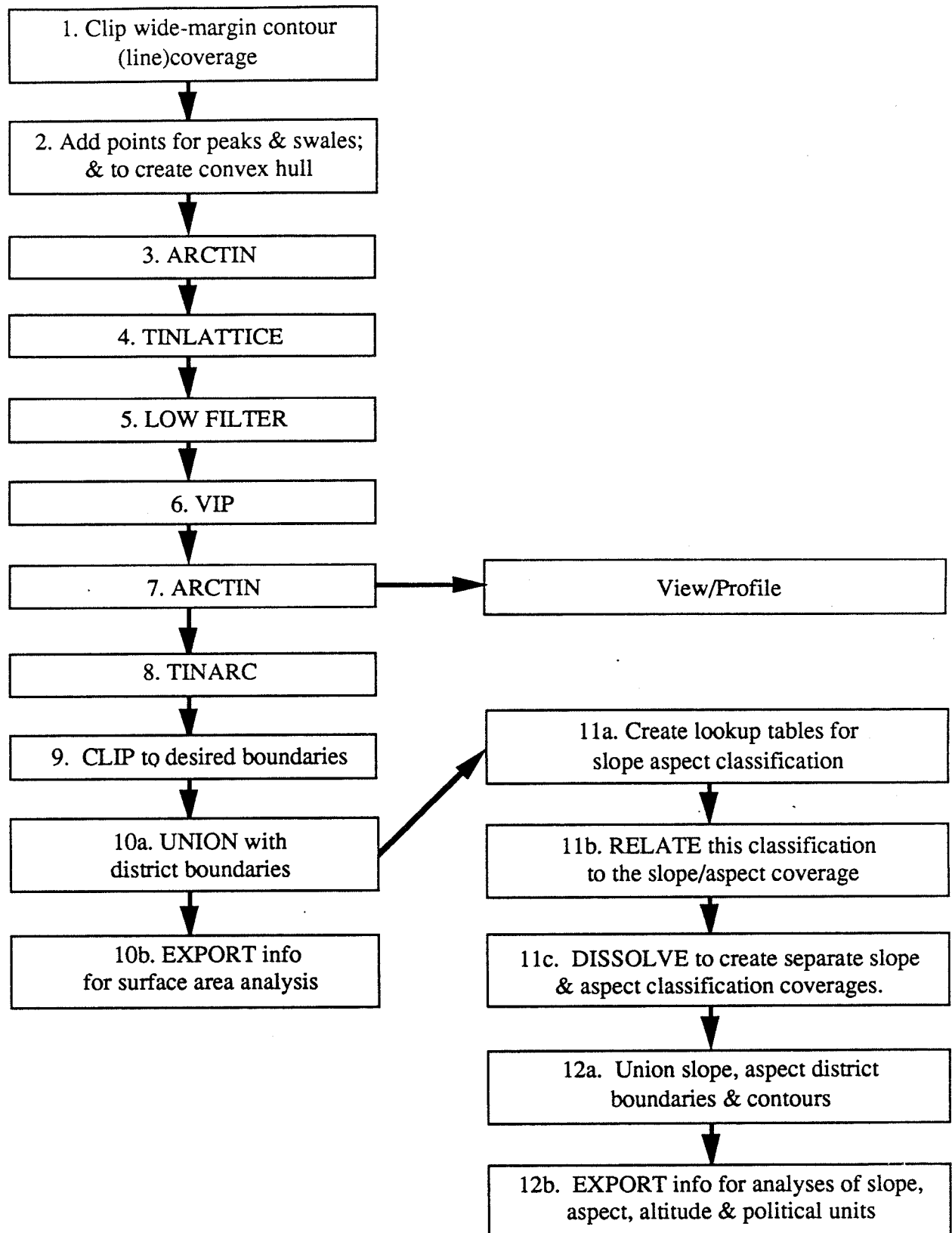
SOLUTION: To resolve this problem, new polygons had to be related to the originals, in order to re-calculate the correct values for surface area.

1. Within ARC: Additem <tin coverage>.PAT <tin coverage>.PAT NEWSAREA 4 12 F 3
2. Within INFO select <tin coverage>.PAT
3. CALCULATE IDSAVE = \$RECNO (This command gives each record a unique identifier that is carried over with the surface area value).
4. Within ARC: Union <tin coverage> <attribute coverage> <new coverage> 10
5. Within INFO: Select <new coverage>.PAT
6. Relate <tin coverage> by IDSAVE
7. CALCULATE NEWSAREA = SAREA * (AREA/\$1AREA)

NEWSAREA now is the correct value in those polygons split as a result of the union procedure.

A good way to check which surface area values have changed is to compare the NEWSAREA and SAREA values. If they are the same, then that is a polygon that wasn't split. If they are different, verify that they represent the same proportion as AREA to \$1AREA.

A TIN FLOWCHART
(numbers keyed to accompanying text)



APPLICATIONS OF A HAND-HELD GPS RECEIVER IN
SOUTH AMERICAN RAIN FORESTS

Michael Baksh*

S12-04
201799
P- 10

ABSTRACT

A hand-held Global Positioning System receiver was used to determine the precise locations of villages, houses, gardens and other cultural and environmental features in poorly mapped South American rain forests. The Magellan NAV 1000 unit provides extremely accurate latitude and longitude information, but determination of altitude is problematical. Overall, the receiver effectively allows anthropologists to obtain essential locational data useful for categorizing land uses, mapping tribal boundaries, and other applications in regions where environmental conditions are harsh and/or accessibility is difficult.

INTRODUCTION

Because many societies live in poorly mapped or unmapped regions of the world, the precise locations of settlements, tribal boundaries, and other cultural and geographic features have, until recently, often been impossible or exceedingly difficult for anthropologists to obtain. With the installation of the U.S. government's NAVSTAR Global Positioning System (GPS), however, locational data accurate to within several meters can now be obtained with relative ease in even the most remote and poorly mapped regions of the world. The development of hand-held GPS receivers in 1989 further facilitates the ability of fieldworkers to obtain precise locational data worldwide.

This paper reports the use of a hand-held GPS receiver in tropical South American rain forests. In particular, Clifford Behrens and I tested a Magellan GPS NAV 1000 receiver in northwestern Ecuador and northwestern Venezuela as part of a National Science Foundation sponsored project studying regional ecology with the use of remote sensed satellite imagery. Indigenous settlements in both regions selected for study are poorly mapped.

While hand-held GPS receivers have been commercially available for less than two years, larger units have been available longer. In an important study in 1988, David Wilkie tested a backpack GPS receiver in the Ituri Forest in Zaire, and reported great success (Wilkie 1989). The unit assembled by Wilkie consisted of a Magnavox 4400 GPS receiver, a two-foot detachable antenna, two 12v gel cells, an ARCO G100 solar panel recharger, and an aluminum backpack, all of which weighed 16 kilos. Among the findings, it was learned that fixes could readily be obtained where the horizon rarely exceeded 30 degrees, and that initial fixes at new spots could usually be obtained within 20 minutes with subsequent position coming within 5 minutes. Wilkie concluded that "the backpack GPS performed well under demanding conditions and was able to obtain three-dimensional positions in inaccessible areas often moderately enclosed by vegetation. The field test ... demonstrated that the use of

*Latin American Center, University of California at Los Angeles.

satellite global positioning technology is a practical means of obtaining accurate geographic location data in inaccessible, poorly mapped regions of the world" (1989:1748). He also concluded that "a backpack GPS should ... be of considerable utility to a wide variety of researchers in remote sensing, archaeology, geography, and ecology" (ibid). Because Wilkie has already demonstrated that mapping and remote sensing applications in tropical rain forests can benefit from GPS technology, this paper focuses on the performance of a newer, hand-held unit.

The Satellite Global Positioning System

The NAVSTAR Global Positioning System currently consists of 15 satellites circling the earth twice daily in fixed orbits 10,900 miles above the surface of the earth. By 1993 there should be a full constellation of 21 satellites with 3 spares, at which time the system will provide 24-hour locational information worldwide.

Developed by the Department of Defense primarily for military purposes, the Global Positioning System provides location and altitude siting to military forces accurate to within 53 feet (about 18 meters). In the current Persian Gulf crisis, U.S. troops on the featureless desert are equipped with GPS receivers, and GPS equipment is also installed on warships, tanks, and aircraft.

The NAVSTAR Global Positioning System was also designed to transmit signals on a channel for civilian use. The public access signals allow for an accuracy of about 30 meters, although it must be noted that the Department of Defense can at any time purposely degrade the accuracy of the GPS's civilian channel, so-called "selective availability."

A GPS receiver calculates a 3 dimensional location fix by "reading" signals from four NAVSTAR satellites which are in known positions. The receiver measures how long it takes to receive a signal from each satellite and, by multiplying it by the speed of light, calculates an estimate of the satellite's distance from the receiver. Using the calculated distance and the known orbital position of each satellite, a receiver computes and displays the receiver's latitude, longitude, and altitude. If altitude is already known, this information can be programmed into a receiver prior to taking a fix, in which case a receiver needs only three satellites to determine latitude and longitude.

Until the full complement of NAVSTAR satellites are in orbit, the hours of coverage for any given spot on the earth will be limited and will vary slightly from day to day. During our work in northwestern Venezuela this past summer, the GPS typically provided about 17.5 hours of 2D coverage and 13.7 hours of 3D coverage per day. The software program SATVIS, written by Rockwell International for IBM compatible microcomputers, allows a user to determine the number of satellites that will be available at any time for any location on earth, taking into account varying angles of visibility above the horizon. Some GPS receivers can now provide similar prior information.

The Magellan GPS NAV 1000

The Magellan GPS NAV 1000 receiver, less than two years old, is one of the first hand-held, easy-to-use units capable of providing extremely accurate information (Figure 1). With a size of 8.75" x 3.5" x 2.13", and a weight of 29 ounces including 6 AA alkaline batteries, the unit is highly portable. The unit is also waterproof, and supposedly floats although we have not yet tested this latter claim.

The NAV 1000 operates in both 2D and 3D modes, and displays position fixes on a backlit LCD. Latitude and longitude data are expressed to 1/100th of a minute, and altitude is expressed in meters or feet. The unit automatically stores the last 5 fixes taken, and can be programmed to store an additional 50 fixes. Regarding accuracy, Magellan Systems Corporation claims that "a position fix accuracy of 30 meters or better is typical" (1989:A-3).

The NAV 1000 receiver also provides reliability information with each fix. Specifically, levels of "Geometric Quality" (GQ) and "Signal Quality" (SQ) are reported. GQ is a measurement of the geometry of the satellites used for triangulating position: the more "spread out" the satellites are, the better the accuracy of the fix. On a scale of 1 to 9, a GQ of 7 or better indicates that geometry is not a problem, whereas a GQ of 3 or less indicates that a fix is unreliable. SQ is an indication of the carrier-to-noise ratio of the weakest satellite being used. On a scale of 0 to 9, an SQ of 4 or better indicates that the weakest ratio is high enough that it will not cause reliability problems.

Perhaps the major drawback to the NAV 1000 is its price tag of about \$3,000, which is still a prohibitive cost for many research projects.

Use of the Magellan NAV 1000 in Ecuador

We took a NAV 1000 receiver to northwestern Ecuador (Carchi and Esmeraldas Provinces) in late 1989 with the objective of pinpointing the locations of several indigenous settlements and gardens. Only a small portion of this region is currently mapped at a scale of 1:25,000, with the next best topographic maps being at a scale of 1:1,000,000.

The receiver worked extremely well in Ecuador, although the times of the day in which signals could be received from an adequate number of satellites were often restricted due to rain forest canopy and mountains rising to 30 degrees or more around many settlements. The availability of open spaces, such as a soccer field in one community clearly eased the ability to obtain a fix, but most indigenous settlements in northwestern Ecuador consist of only a few huts in small clearings. Still, we were able to obtain a fix at a different community everyday, although in one case it was necessary to tie the unit to a 3 meter long pole and raise it above the roof of a hut during a rainstorm. Success in locating cattle pastures and beaches was also obtained with little difficulty.



Figure 1. The Magellan NAV GPS Receiver.

The latitude and longitude data obtained in Ecuador served two purposes. First, we were able to more precisely locate settlements so as to determine whether cloud-free LANDSAT and SPOT images were available for land cover/land use classification and ecological analysis. As it turns out, cloud-free images are currently not available for this proposed study site. However, while this was an unfortunate development, the important point is that this type of search could not have been conducted with great confidence without detailed locational data.

A second application for these data is that Ecuadorean government agencies working to establish an Awa Indian Reserve now have precise information useful for pinpointing the location of several communities on maps they are constructing for a variety of research and conservation purposes.

Use of the Magellan NAV 1000 in Venezuela

The NAV 1000 was also used this past summer in Venezuela to collect locational data for a regional ecological study of the Bari Indians. Based upon the performance of the unit in Ecuador, we initially felt that this paper would be a glowing, commercial-like advertisement for Magellan Systems Corporation. Unfortunately, our unit failed after only two weeks into fieldwork, and well before opportunities were available to collect crucial locational data from all but one community. Our initial enthusiasm over the unit is therefore temporarily on hold, and our ability to evaluate the effectiveness of the unit under field conditions is restricted. This paper is therefore not as positive or informative as it could have been, although it must be noted that Magellan has repaired and upgraded our unit so we are hopeful that the necessary data will be obtained over the next year.

Aside from wanting to collect locational data for mapping, remote sensing, and applied purposes, another objective this summer was to conduct experiments on the performance of the unit. In particular, we wanted to test the accuracy of its fixes, and to determine the extent to which its "Geometric Quality" and "Signal Quality" information serve as measures of data reliability.

This reliability exercise involved taking multiple fixes from the same location in the Bari community of Saimadoyi. This spot was in the middle of the village soccer field, where unobstructed access to the sky was maximized (Figure 2). Still, the horizon to the east was blocked by a mountain ridge rising to 30 degrees, and the horizon in all other directions was obstructed by village huts, trees, and distant mountains (Figure 3).

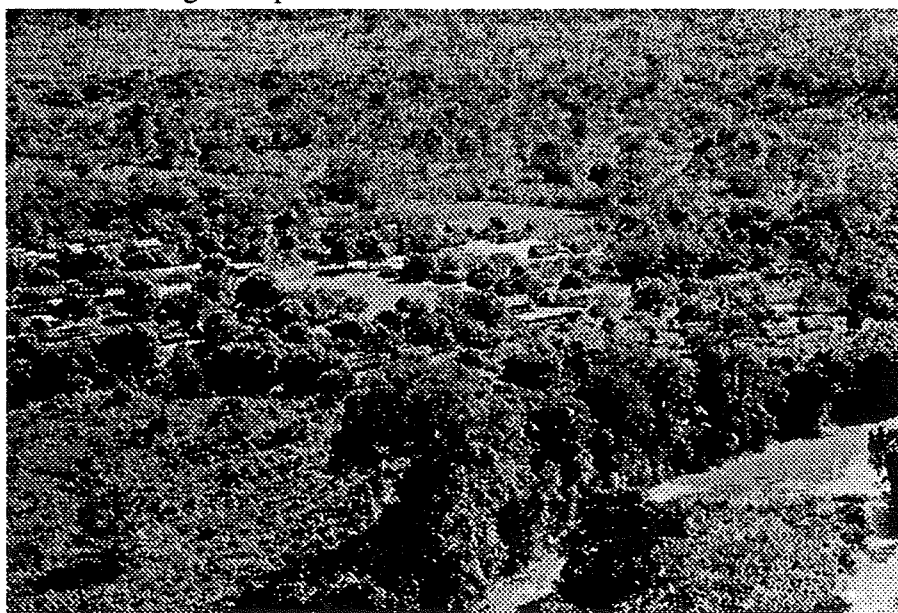


Figure 2. Soccer field in Saimadoyi, Venezuela used to field test reliability of Magellan NAV 1000 GPS receiver.

A total of 37 fixes was obtained from this

230



Figure 3. Westward view of Saimadoyi, Venezuela and the Sierra de Perija.

spot before the receiver malfunctioned. Twenty of these trials were 2D fixes, and 17 were 3D. Thirty of the 37 trials (81%) resulted in fixes for which both GQ and SQ were of high or medium reliability.

Of the 37 trials, 10 yielded fixes for which both GQ and SQ were high, that is, with reliability levels of 7-9. In an effort to determine the exact or "true" location of this experiment, the latitude and longitude measurements of these 10 fixes have been averaged. This "true" location where all 37 trials were taken is estimated to have been situated at $9^{\circ} 35.985'$ north latitude and $72^{\circ} 54.583'$ west longitude. By plotting the 10 high quality fixes in relation to this point (Fig.4), using 18.5 meters per $1/100$ of a minute for latitude and 18.3 meters per $1/100$ of a minute for longitude (based upon the respective circumferences of the earth at this point), it is calculated that the average high quality trial yielded a fix that was 35 meters away from the true location. Although 4 of the 10 fixes are estimated to have been only 9 meters away, 1 fix was approximately 92 meters away (Table 1).

Of the 37 fixes, 15 yielded a high GQ and a medium SQ. By plotting these 15 fixes in the manner described above (Fig.5), it is calculated that fixes with these levels of reliability yield an average "accuracy" of 44 meters. Similarly, fixes with a GQ of medium and a SQ of high or medium ($N=5$) yielded an average error of 95 meters, and fixes with unreliable GQ and/or unreliable SQ ($N=7$) yielded an average error of 124 meters. Of interest, by superimposing the plot of all 37 fixes over a map of the community, all but one fix falls within the village and about half are on the soccer field itself.

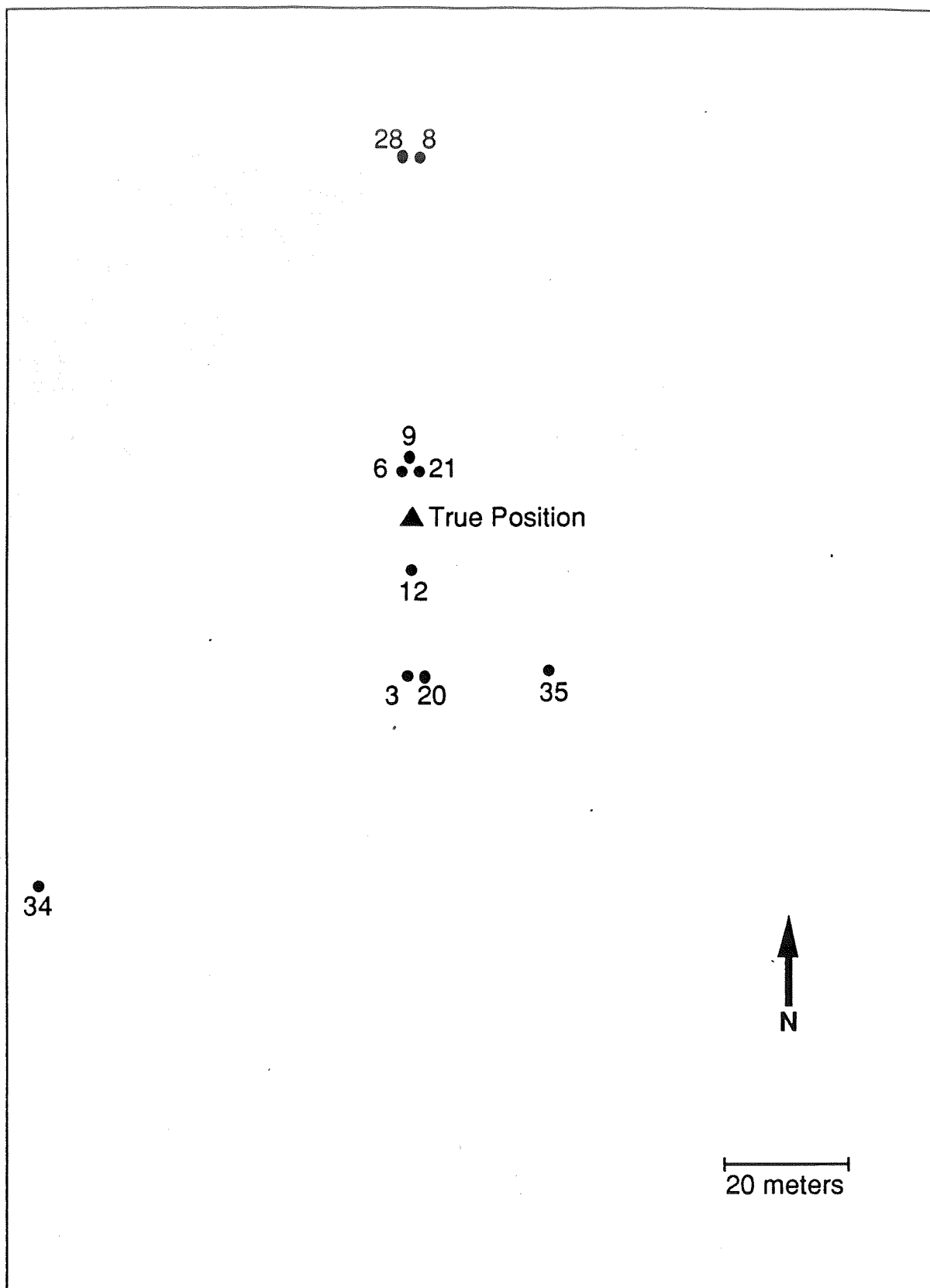


Figure 4. Plot of the 10 fixes of high reliability in relationship to the calculated "true" position of 9° 35.985' N and 72° 54.583' W.

Table 1. Locational and Reliability data Collected from a Single Site by a Magellan GPS NAV 1000 in Saimadoyi, Venezuela.

Reliability		Latitude North	Longitude West	Estimated Distance (Meters) From "True" Location*	Altitude (Meters)	Fix Number
GQ	SQ					
High	High					
9	8	9° 35.99'	72° 54.58'	9	150**	9
9	8	9° 35.99'	72° 54.58'	9	150**	6
9	7	9° 35.98'	72° 54.58'	9	150**	12
9	7	9° 36.02'	72° 54.58'	65	150**	28
9	7	9° 35.95'	72° 54.62'	92	150**	34
9	7	9° 35.97'	72° 54.57'	36	150**	35
8	8	9° 35.97'	72° 54.58'	28	155	3
8	7	9° 35.97'	72° 54.58'	28	140	20
8	7	9° 35.99'	72° 54.58'	9	197	21
7	9	9° 36.02'	72° 54.58'	65	193	8
High	High					
9	6	9° 35.99	72° 54.59'	15	98	22
8	6	9° 36.00'	72° 54.59'	30	125	2
9	5	9° 35.96'	72° 54.57'	48	110**	1
9	5	9° 35.95'	72° 54.58'	65	150**	5
9	5	9° 36.00'	72° 54.56'	51	150**	23
9	5	9° 35.99'	72° 54.57'	27	150**	25
9	5	9° 36.01'	72° 54.57'	52	150**	26
9	5	9° 35.99'	72° 54.57'	27	150**	36
9	4	9° 35.98'	72° 54.58'	9	150**	27
9	4	9° 35.95'	72° 54.56'	78	150**	33
9	4	9° 36.05'	72° 54.53'	152	150**	37
8	5	9° 35.99'	72° 54.58'	9	150**	11
7	7	9° 36.00	72° 54.58'	28	143	10
7	5	9° 36.00'	72° 54.59'	30	31	16
7	5	9° 35.98'	72° 54.56'	43	53	19
High	High					
5	7	9° 35.93'	72° 54.57'	104	150**	30
5	7	9° 36.06'	72° 54.57'	140	263	7
High	High					
6	5	9° 35.95'	72° 54.58'	65	150**	31
5	6	9° 36.00'	72° 54.58'	28	45	15
4	4	9° 35.91'	72° 54.59'	139	-270	4
unreliable						
9	3	9° 36.02'	72° 54.57'	70	150**	29
4	3	9° 35.94'	72° 54.61'	97	341	18
7	2	9° 36.03'	72° 54.58'	83	150**	24
2	6	9° 35.96'	72° 54.56'	59	-446	14
1	5	9° 35.89'	72° 54.80'	433	763	17
1	4	9° 35.96'	72° 54.56'	59	37	13
1	1	9° 36.01'	72° 54.61'	67	150**	32

* The "True" location is estimated to be 9° 35.985' N and 72K 54.583' W.

** Altitude programmed into the receiver for 2D fixes.

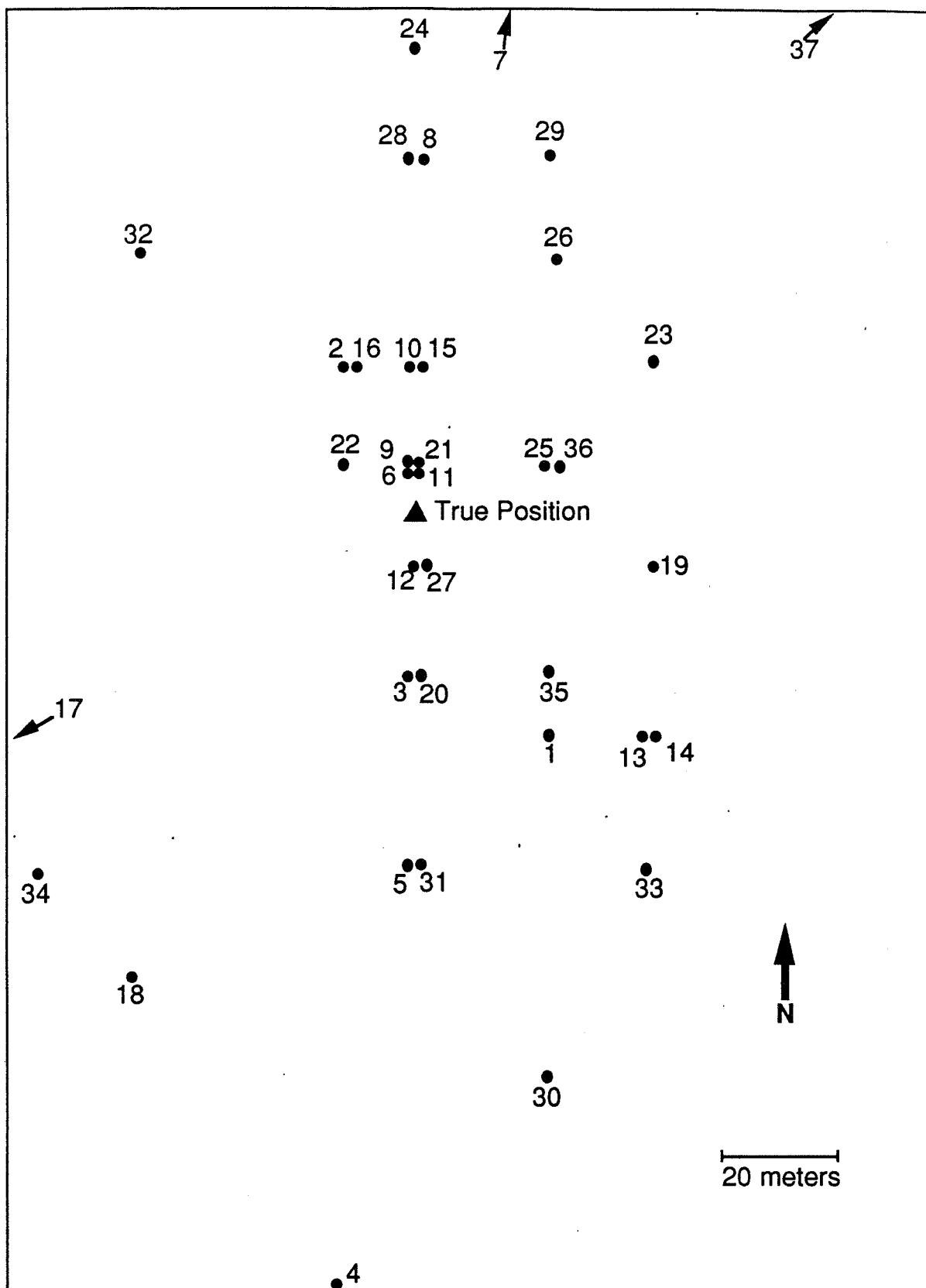


Figure 5. Plot of all fixed in relationship to the calculated "true" position of $9^{\circ} 35.985' \text{ N}$ and $72^{\circ} 54.583' \text{ W}$.

One implication of these findings is that high accuracy is especially dependent upon achieving a high GQ. A high SQ is also advantageous but a medium SQ does not seriously impact the accuracy of a fix obtained with a high GQ.

Perhaps the most important observation of this exercise is that high accuracy can be achieved simply by taking multiple fixes from a given location. Thus, by averaging the 15 fixes of high GQ and medium SQ, the distance from the "true" location where these fixes were taken is 21 meters. Similarly, averaging the 5 fixes for which medium GQ reliability was obtained puts the receiver 30 meters from the true location, and averaging the 7 fixes for which unreliable data were obtained puts the receiver within 55 meters.

From a practical standpoint, a fieldworker needing an accuracy of, say 20 to 30 meters, should be able to gain this with 5 to 10 fixes, assuming that over half of these yield a high or medium GQ. Measurements of the time required to obtain fixes by the NAV 1000 indicate that about 2 minutes and 48 seconds are required for 3D (N=10) and 2 minutes and 15 seconds for 2D (N=15). This means that 5 to 10 fixes can easily be obtained and recorded in less than a half hour. If the anthropologist's time is not a major constraint, extremely high accuracy can be achieved by making even more fixes.

Accurate altitude location is more difficult to achieve than latitude and longitude position with the NAV 1000, although this problem may be more a consequence of the NAVSTAR GPS than the receiver itself. Based upon the scrutiny of two altimeters and a topographic map, the trials described above were taken at about 150 meters above sea level, yet the average altitude of the 17 3D trials is 91 meters. The most distressing observation of the altitude data is that the range of these 17 trials was from 763 meters above sea level to 717 meters below sea level! Unfortunately, even throwing out the "unreliable" fixes (i.e., those with reliability levels of 3 and less) does not help much, since the fix of 717 meters below sea level was achieved with medium levels of reliability (GQ=4, SQ=4). By averaging the 10 3D trials for which high GQ and SQ reliability levels were achieved, a reasonable altitude of 126 meters above sea level is obtained, but the range of 197 meters to 31 meters above sea level is still rather high. Based on this exercise, accurate altitude information is better achieved with the use of a good altimeter. And because 2D fixes can be obtained more often (at least until the full constellation of satellites is functioning) and more easily than 3D fixes, greater flexibility in the collection of latitude and longitude data is afforded whenever one can program a receiver with known altitude information.

Our evaluation of the performance of the Magellan NAV 1000 receiver will continue over the next year as the precise locations of Bari villages, hunting camps, gardens, cattle pastures, certain soil and vegetation types, and abandoned longhouse sites are obtained. And in addition to collecting ground truth data for supervised classification of satellite imagery, the receiver will be used to plot the course of a fence being constructed by the Bari in an effort to establish a physical barrier to protect what remains of their tribal territory from encroachment by colonists, developers, and other outsiders.

CONCLUSIONS

The Magellan GPS NAV 1000 was found to be an invaluable tool for obtaining highly accurate latitude and longitude information useful for both research and applied purposes. In particular, we

have used this new technology to locate indigenous settlements in poorly mapped regions. With it we also plan to collect ground truth data for satellite image classification and to assist the Bari in defining more precisely the legal limits of their Reserve. The ruggedness of the NAV 1000 remains a bit suspect, however, considering that our unit survived a total time of only about two months in tropical rain forests. We would like to think either that our unit was characterized by a rare manufacturing flaw, or that new models will be more durable because when the receiver works, it really works well.

ACKNOWLEDGEMENTS

The fieldwork conducted for this paper was supported by a National Science Foundation research grant (BNS 89-11090).

I wish to thank Carlos Villarreal and James Levy of the Unidad Tecnica Ecuatoriana del Plan Awa (UTEPA) for their assistance in arranging field work in Ecuador. I also wish to acknowledge Roberto Lizarralde of the Universidad Central de Venezuela for helping to make possible research among the Bari.

REFERENCES

Magellan Systems Corporation 1989 Magellan GPS NAV 1000 User Guide. Monrovia, CA.

Wilkie, David S. 1989 Performance of a Backpack GPS in a Tropical Rain Forest. Photogrammetric Engineering and Remote Sensing 55(12):1747-1749.

CONTINUOUS COST MOVEMENT MODELS

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS.

W. Fredrick Limp*

513-43
201800
p- 11

ABSTRACT

Use of current space imaging systems and airborne platforms has direct use in survey design and site location when used in concert with a comprehensive GIS environment. Local conditions and site physical and chemical properties are key factors in successful applications. Conjoining of environmental constraints and site properties are present for the later prehistoric occupations in the Arkansas and Mississippi River areas. Direct linkages between comprehensive site databases and satellite images can be used to evaluate site distributions for research and management.

INTRODUCTION

The various papers in this volume are addressing the manner in which a suite of technologies, particularly remote sensing and geographic information systems, can be applied to anthropological problems. In this paper I would like to use a substantive example to consider how the interaction of technologies can affect our development of theory.

In the 1970s a very common archeological approach to the study of land use involved the application of a simple model derived from the geographic literature. This approach considered the utilization of the landscape around a location to be a function of the distance from the location (Chisholm 1962, Hoover 1948, Haggett 1960).

In archeological applications such an approach was termed "site catchment analysis" (Vita-Finzi and Higgs 1970, Higgs and Vita-Finzi 1972, Roper 1979, Flannery 1976). In general the approach involved the drawing of a number of concentric circles around a location and evaluating the relative resources available in circles of increasing distance from the point of origin.

While the model contributed significantly to improving understanding of potential landscape use, it rightly fell under increasing criticism. These criticisms emphasized that the use of the landscape was complex, with a mix of differing strategies including extra-local travel. (Limp and Carr 1986:150-157)

While such criticisms were and are fully valid I am also of the opinion that a major deterrent to continuing use of such a model was the very simple fact that modeling landscape use with uniform circles was patently inappropriate except in the modeler's hypothetically uniform environment.

Recognizing the continuing validity of the criticism that landscape use is complex with significant extra-local factors, I would like to present a methodological improvement to the approach that I believe can reinvigorate it's use.

*Arkansas Archeological Survey

PROBLEM

Such an approach relies on the technologies of a "geographic information system" (Burrough 1986) and increases the realism of the landscape modeling effort. In addition it allows easy integration of any other data available in the GIS including soils data and remote sensed imagery.

In this approach the landscape is visualized as a continuous surface (rather than a set of polygons) and it is modeled as a grid of potentially diminishing size (Kvamme 1989:151-153). In this grid each cell has a series of attributes, some or all of which may influence travel across the grid location. Attributes include factors such as elevation, slope and soil texture.

The attributes may be biophysical or social or a mix of both. The attributes can be combined in a variety of ways. For example travel may be affected by a location's slope, the density of its vegetation and the need to avoid coming into close proximity with another group's territory. When combined and considered together the attributes are termed a "continuous cost surface", where the cost is the effort required to traverse the cell. These values can also be viewed as the location's friction.

In a simple example the slope at each grid location might be viewed as a measure of the cost required to traverse the location. With any given cost surface the GIS can compute a cumulative cost surface. The cumulative cost surface is computationally derived by moving outward from the starting point in all directions and summing the individual unit costs. It is possible to draw contours of equal cumulative cost or iso-cost contours on this cumulative cost surface. These iso-cost curves are comparable, then, to the defined circular catchments but with the considerable improvement of factoring into the model the actual landscape properties. A secondary, but by no means insignificant, feature of the approach is that the GIS can also be used to compute the various areas of the soils or other catchment properties.

With this brief background I will illustrate the use of the continuous cost surface model with data from the Rush Project. The project involved large scale excavations of a site which was occupied by late prehistoric agriculturalists.

Figure 1 shows the location of the project on the Buffalo River. The map presents the elevation for the area with the lower elevations in green and the highest in bright yellow and is derived from USGS Digital Elevation Model data for the area. The Rush Project has been underway for the last three years along the Buffalo National River in the highly dissected Ozark Mountains of north central Arkansas. It is a cooperative project of the National Park Service and the Arkansas Archeological Survey. Additional archeological details are available in Sabo et al (1990).

The traditional catchment analysis looks at a site's resource potential in a series of concentric rings of increasing distance from the site. A presumption of such concentric rings is that travel is equally feasible in all directions at an equivalent "movement cost." Anyone visiting the Rush Project area immediately recognizes the fallacy of such a view. In many places the walls of the

Buffalo River Valley are so steep and tall as to be virtually impassable.

Figure 2 shows the immediate area of the site in 3-D. The site proper is located adjacent to the main valley at the point where the two tributary streams enter from the northwest.

I will briefly consider the results of a traditional catchment analysis of the site with respect to agriculturally productive soils. Our primary purpose is simply to provide a contrast to the later, more realistic cost surface catchment models.

Figure 3 shows the distribution of the area's agricultural soils in 3-D draped over the area's elevation. Based on soil properties the soils were reclassified into four agricultural capability classes considering the agricultural varieties and techniques of the prehistoric inhabitants. Using the GIS capabilities we can tabulate the occurrence of the various categories of each capability class. If the Rush inhabitants were practicing agriculture, we might propose that the site would be located such that agriculturally productive soils were located in reasonably close proximity to the site.

Table 12-1 compares the hectares and percentages of each capability class for each of the catchments.

Table 1. Agricultural capability for circular catchments.

Catchment	Primary		Secondary		Marginal		Unlikely	
	ha	%	ha	%	ha	%	ha	%
0 to 1 km	5.4	1.7	37.8	12.0	60.1	19.0	212.8	67.3
1 to 2 km	15.2	1.1	160.9	17.3	71.2	7.6	684.4	73.5
2 to 3 km	15.6	1.0	215.6	13.9	282.5	18.2	1036.8	66.9
3 to 4 km	22.9	1.1	382.3	17.7	239.1	11.1	1518.6	70.2
4 to 5 km	59.6	2.2	393.2	14.6	594.5	21.4	1726.8	62.2
Total Area	1.1		16.1		15.1		67.6	

Total Area includes areas not within catchments.

Examination of the table indicates that, while there may be a slightly greater percentage of primary agricultural soils in close proximity to the site, the relationship is by no means strong and may easily be due to any of a number of factors not related to the site itself. We must admit, however, that the discovery of any patterning with these circular catchments would have come as a considerable surprise given the area's topography. Having briefly considered this traditional approach, we will quickly turn to what we believe is a much more realistic one.

As a first approximation we can presume that as a location's slope increases it becomes increasingly more costly to move across that location. The digital slope data is derived from elevation data.

In assigning a cost (or coefficient of friction) to each location based on its slope, the next issue becomes how to measure this cost. We have a slope value for each 30 m cell in the study area

with the values ranging from 1 to 43 degrees of slope. We might wish to simply use these values. In doing so we would be presuming that as slope increases the cost increases linearly. Thus, a location that has a slope of 20 degrees is four times more difficult to traverse than a location with only 5 degrees of slope. While such a view has merit, I feel it more reasonable to presume that as slope increases it becomes significantly more difficult to traverse the location. One way to model this would be to compute the cost to be increasing as the square of the slope. (There are a number of interesting implications to this approach which are beyond the scope of this paper). The computation then creates a surface in which each cell has as its value the cost of traversing it. The cumulative cost surface is created by effectively radiating out from the point of origin in all directions and adding the values encountered in each cell. Using this logic we can produce a cost movement surface radiating outward from the Rush site.

In Figure 4 the elevation data is shown in the upper left of the slide and the slope in the upper right. The brighter colors represent steeper slope classes. The lower images are the cost catchments with the left the catchment resulting from ignoring the river and the right the catchment which factor in the river as a barrier to travel.

Figure 5 is an image of the catchment surface "draped" over the area's elevation. As would be expected, this catchment map is quite irregular in shape, reflecting the relative ease with which movement is possible up and down the Buffalo River Valley, as well as the relative ease of moving up the Rush and Clabber Creek valleys to the northwest. Both of these provide a relatively easy route out of the main valley to the uplands, an option which is not available at many locations in the Buffalo River.

As we did for the circular catchment we can investigate the relative occurrence of potential resources within variable catchments around the site. For purposes of comparison, it would be useful to have catchments which are equivalent to the circular catchments. The traditional circular catchment implies in essence that the cost of traversal of all locations is uniform, i.e., that each cell has a friction or cost-to-traverse of one. In the following a catchment which is the "effort" equivalent of each circular catchment is computed by using the cumulative cost curves. The amount of the area encompassed by the cost catchment will be considerably less than the equivalent circular catchments. With this in mind, however, we can use these means for assessing some rough comparability between the two. Table 2 indicates the agricultural capabilities for each cost catchment.

Table 2. Agricultural capability for cost catchments.

Catchment	Primary		Secondary		Marginal		Unlikely	
	ha	%	ha	%	ha	%	ha	%
Cost = 1 km	0.4	0.3	0.9	0.6	34.7	24.5	105.2	74.6
Cost = 3 km	18.6	4.1	5.9	1.3	121.3	26.7	309.3	67.9
Cost = 5 km	47.0	4.7	20.5	2.0	290.5	28.8	650.2	64.5
Cost = 10 km	78.8	3.2	84.3	3.4	863.9	34.5	1476.1	59.0
Total Area		1.1		16.1		15.1		67.6

Total Area includes areas not within catchments.

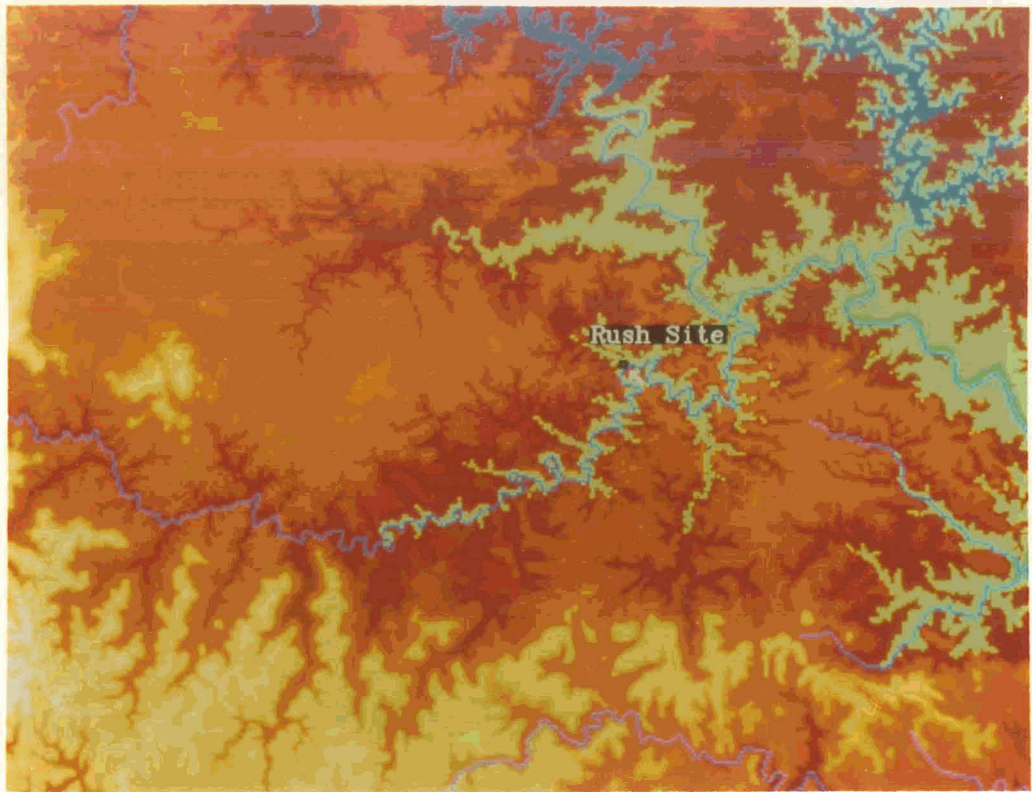


Figure 1.

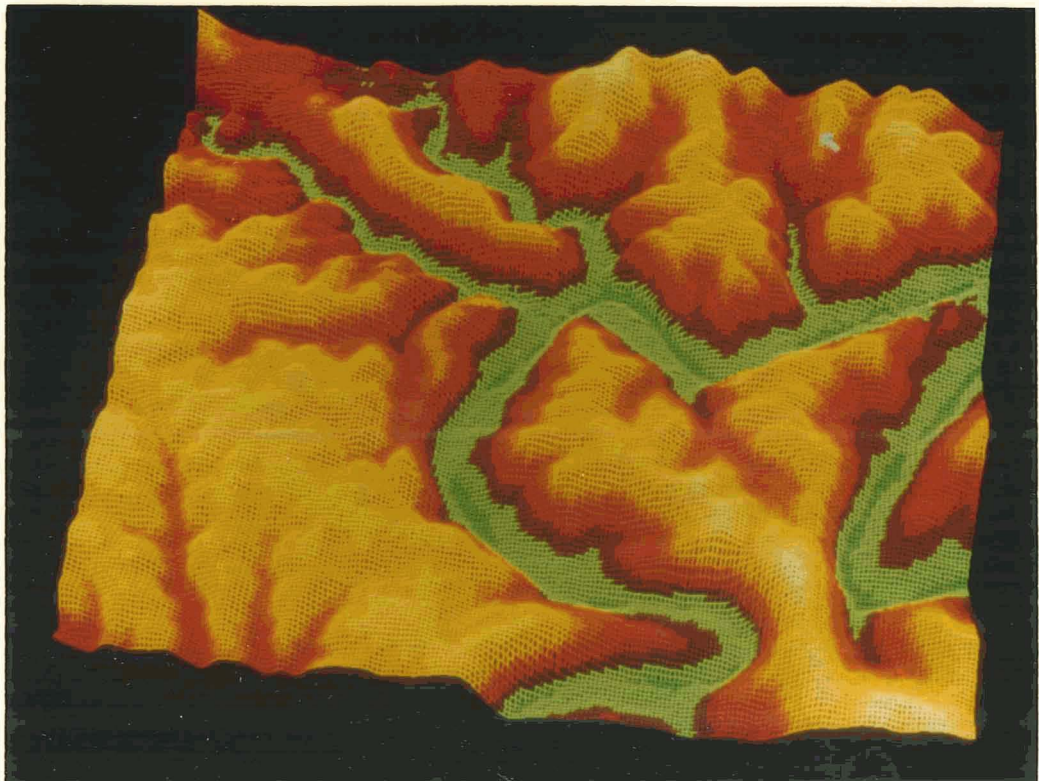


Figure 2.



Figure 3.

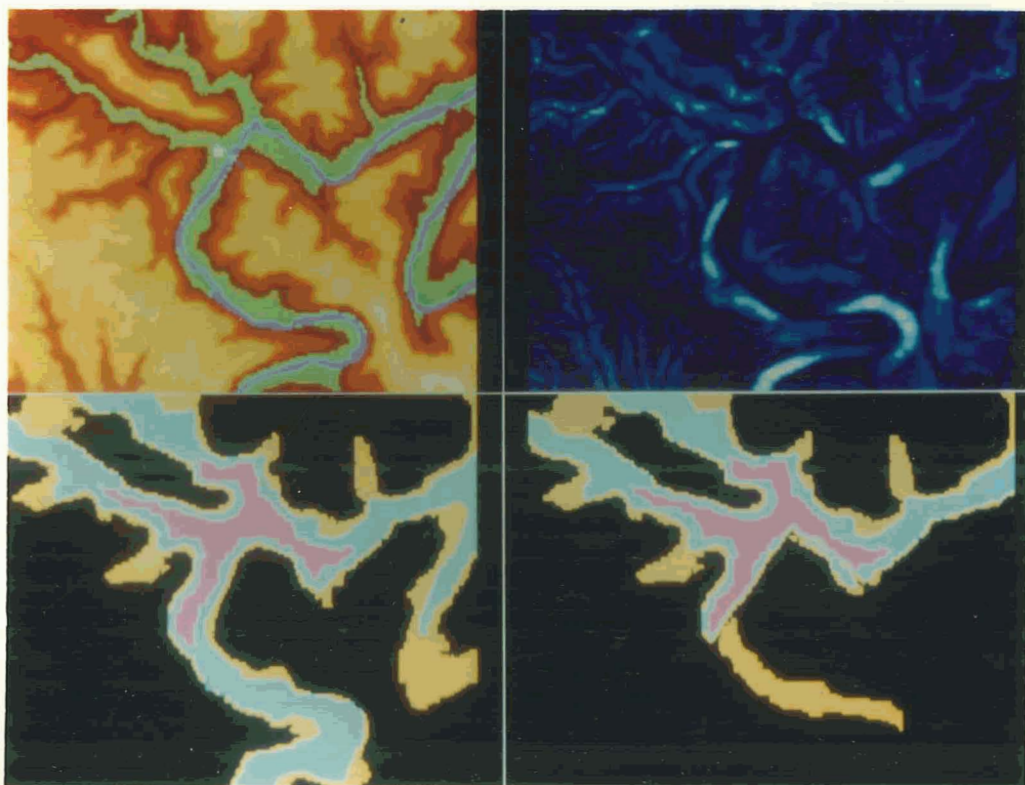


Figure 4.

Because the catchments are quite a bit smaller than the circular ones, we have added a 10 km equivalent catchment to the table. As we examine these values and compare them with the circular catchments, a number of interesting patterns emerge. First, the cost surface model has considerably greater percentages for the primary agricultural soils than did the circular model, though in both cases the numbers are small. Conversely, the cost model has greater percentages in the unlikely class. It seems reasonable to ascribe this structure to the following situation. The site is well situated to take advantage of the floodplain areas, both for their agricultural potential (for the later groups) and for the abundance of floodplain plants and animals that would be present. In addition, however, the site was also well suited to allow utilization of the extensive uplands and the many wild resources available in that location. Based on the data available, if the later site inhabitants were practicing agriculture (or horticulture), there would have been other locations in the Buffalo River Valley which would have provided closer proximity to primary agricultural soils, but these locations would not have had the easy access to the uplands that the Rush Creek and Clabber Creek valleys provided.

Although the addition of slope to the movement modeling process increases its realism, it is clear that there are other factors that may influence the ability of an individual to travel. In the Rush area an obvious factor is the Buffalo River itself. In this part of the valley it is a stream of some considerable size (ca. 25 m wide) and, particularly after rains, it would be quite difficult to cross.

Figure 6 and Table 3 illustrate the cost catchments which are a result of factoring the river as a barrier to travel. Comparing these catchments to the earlier model, we can see that movement upriver (to the south) is possible for some distance but is finally blocked when the river swings up against the steep bluff. It is important to emphasize that the model recognizes only current conditions. The river's location within the valley undoubtedly changed during the period the site was occupied. We believe that it is reasonable to presume, however, that while the exact location where the river encounters the bluff (blocking travel) may have changed, such a situation would have existed prehistorically somewhere within the area. If the river did influence travel in such a manner, then the accessible locations up the Rush and Clabber Creek valleys become of even greater consequence.

Table 3. Agricultural capability for cost catchments where the river is a barrier to travel.

Catchment	Primary		Secondary		Marginal		Unlikely	
	ha	%	ha	%	ha	%	ha	%
Cost = 1 km	0.0	0.0	0.9	0.7	26.3	20.9	98.6	78.4
Cost = 3 km	9.6	2.9	5.6	1.7	93.9	28.4	221.7	67.0
Cost = 5 km	14.6	2.7	11.5	2.1	153.8	27.9	370.8	67.3
Cost = 10 km	36.1	2.2	37.6	2.3	622.1	38.6	916.3	56.8
Total Area	1.1		16.1		15.1		67.6	

Total Area includes areas not within catchments.

If the river was a barrier, then it would have substantially reduced the availability of primary and even secondary agricultural soils. In the first model there were 18.6 ha of primary agricultural soils within the "3 km" cost catchment. Adding the river as a factor in accessibility, then the amount of primary agricultural soils within the catchment falls to only 9.6 ha. Not only does the absolute amount decline, as would be expected if an additional limit was placed on movement, but the relative amount of the primary soils also decreases. Clearly, access to agricultural soils across the river was a factor in the earlier model.

It is important to emphasize that the model recognizes only current conditions. The river's location within the valley undoubtedly changed during the period the site was occupied. We believe that it is reasonable to presume, however, that while the exact location where the river encounters the bluff (blocking travel) may have changed, such a situation would have existed prehistorically somewhere within the area. If the river did influence travel in such a manner, then the accessible locations up the Rush and Clabber Creek valleys become of even greater consequence.

If the river was a barrier, then it would have substantially reduced the availability of primary and even secondary agricultural soils. In the first model there were 18.6 ha of primary agricultural soils within the "3 km" cost catchment. Adding the river as a factor in accessibility, the amount of primary agricultural soils within the catchment falls to only 9.6 ha. Not only does the absolute amount decline, as would be expected if an additional limit was placed on movement, but the relative amount of the primary soils also decreases. Clearly, access to agricultural soils across the river was a factor in the earlier model. We could further refine the model by viewing the river not as an impediment to travel but as a facilitator via waterborne transport. We will not apply this approach here because of the limited area for which we have digital data. A similar study indicated that, depending on the cost factors, such an approach would open up a considerable extent of the Buffalo River Valley to the model.

In viewing these models it is clear that the Rush site's location is one from which both floodplain and non-floodplain resources are accessible. It is not the "best" location for either, but it clearly is superior for a mixed strategy which utilizes both zones. While the Rush site's location provides access to the uplands resources, it also may be important that the site's location provides access for travel in and out of the valley, perhaps facilitating trade or other activities which require more distant movement.

CONCLUSIONS

There are many additional improvements which could be made to the modeling process. Consideration of the river as a facilitator of travel has already been noted and other factors could also be included. In addition, it is possible to use the same cumulative cost surfaces to determine least cost routing from a location to the site.

Beyond these technical issues I would like to close by considering, briefly, the interesting but often ignored dynamic between technical method and theory. As I have noted earlier the "demise" of catchment theory is due in large part to the valid criticisms leveled at it, but I am also convinced that a more fundamental issue was the inherent deficiency in the technical implementation of the model which essentially required that the surface be modeled as a uniform circle. In some few

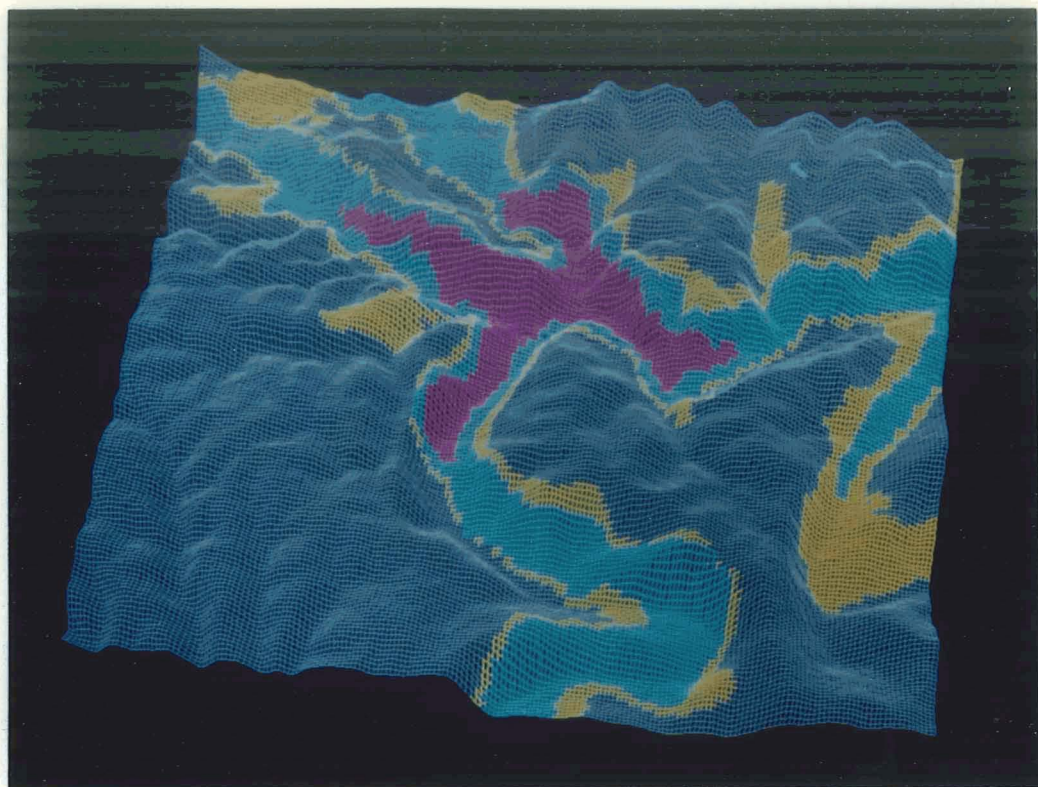


Figure 5.

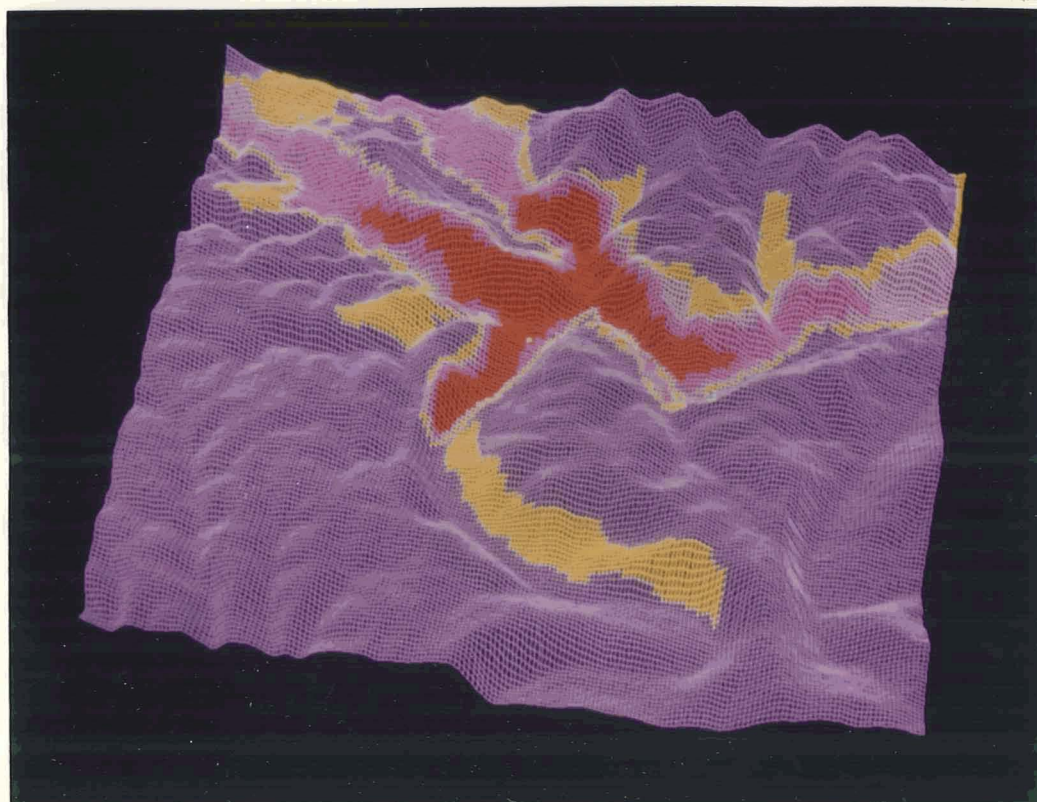


Figure 6.

situations more realistic examples were laboriously created, factoring in the area's actual topography. These realistic efforts were so labor intensive that the results simply didn't merit the work. Today, with the GIS, a variety of complex surface models are readily available, once the basic data acquisition is complete. (No small task that.) Because alternative approaches can be easily computed, the approach takes on the guise of "EDM" or "exploratory data modeling" (to modify slightly the idea of exploratory data analysis). I have used the example of catchment studies but there are many other similar areas in which the application of automated techniques has (or can) address central methodological limitations to theory building or testing.

I am not convinced, however, that such methodologies are having a significant impact on current theory builders in anthropology and archeology. The situation should mirror that of physics where the theoretical and experimental physicists apparently dislike each other but stand in mutual need and even grudging respect. I do not currently see such a maturity in our field. This is probably due in large part to the considerable initial investment in both time and resources that is involved to become "fluent" in these techniques. The costs of these technologies will continue to fall but there will remain a substantial requirement for training. I am also convinced, however, that there is a current emphasis in anthropology and archeology away from what might even be faintly classified as quantitative methods. I hope that meetings such as this one will provide the bridges between these camps and lead to more productivity in both.

ACKNOWLEDGEMENTS

The Rush Project was funded through a cooperative agreement between the National Park Service and the Arkansas Archaeological survey. George Sabo served as Principal Investigator for the first phase and Charles Ewen for the second phase. Randall Guendling was site supervisor. A number of members of the Arkansas Archaeological Society donated valuable time to the project. Margaret Guccione, Susan Scott, Gayle Fritz and Pamela Smith contributed the report on the first phase. James Farley, Jami Lockhart, Bob Harris and Wong Song assisted in the computer analysis. The Rush Project would not have been possible without the contributions of Walter Wait.

REFERENCES

- Burrough, P. 1986 Principle of Geographic Information Systems for Land Resource Assessment. Clarendon Press. Oxford.
- Chisholm, M. D. I. 1962 Rural settlement and Land Use: An Essay in Location. Hutchinson. London.
- Flannery, K.V. (ed) 1976 The Early Mesoamerican Village. Academic Press. New York.
- Haggett, P. 1960 An Locational Analysis in Human Geography. St. Martin's. New York.
- Higgs, E. and C. Vita-Finzi 1972 "Prehistoric economies: a territorial approach". In E. Higgs (editor) Papers in Economic Prehistory. Cambridge University Press. Cambridge. pages 27-36.

Hoover, E. M. 1948 The Location of Economic Activity. McGraw-Hill. New York.

Kvamme, K. 1989 "Geographic Information Systems in Regional Archeological Research and Data Management". In M. B. Schiffer (editor) Archeological Method and Theory 1:139-203. University of Arizona Press. Tuscon.

Limp, W. F. and C. Carr 1986 "The Analysis of Decision Making:Alternative Applications in Archaeology". In C. Carr (editor) For Concordance in Archeological Analysis. Westport Press. Kansas City. pages 128-172.

Sabo, G., R. Guendling, W.F. Limp, M. Guccione, S. Scott, G. Fritz and P. Smith 1990Archeological Investigations at 3MR80-Area D in the Rush Development Area, Buffalo National River Arkansas. Southwest Cultural Resources Center, National Park Service, Professional Papers No. 38. Santa Fe.

Vita-Finzi C. and E. Higgs 1970 "Prehistoric Economy in the Mount Caramel area of Palestine: Site Catchment Analysis". Proceedings of the Prehistoric Society 36-1-37.

TRADITIONAL ANTHROPOLOGY AND GEOGRAPHICAL INFORMATION SYSTEMS IN THE COLLABORATIVE STUDY OF CASSAVA IN AFRICA

Steven Romanoff*

5/4-82
201801
R 10

ABSTRACT

Cross-cultural, village-level, and farmer surveys have been used with a geographical information system to describe the distribution and relative importance of cassava (manioc, yuca, Manihot esculenta) in its cultural, economic, and ecological contexts. It presents examples of data management for mapping, sample selection, cross-tabulation of characteristics, combination of data types for indices and hypothesis testing. This paper reviews the methods used and presents some of the main conclusions of the study.

INTRODUCTION

Anthropological knowledge of culture is rarely combined with the kinds of remote sensing data being discussed in this seminar. Yet traditional cross-cultural studies, such as those presented in the journal Behavior Science Research published by the Human Relations Area Files (HRAF), or the classic culture-trait distribution studies done under Kroeber at the University of California, share characteristics with satellite imaging. Among them are broad geographic scope, concern with spatial patterns, attention to problems of coding, and, sometimes, interest in change.

Since geographic information systems process data from any source with equal ease, there is no insurmountable barrier to combining social or cultural data with data from non-social science sources, so long as the cultural data are relatively uniform and in coded form.

This paper reports the methods used in a continuing study of Cassava production, processing, and marketing in Africa to match data on cultures and villages with census and climatological data. These experiences stop short of using remote sensing information, but the methods can be extended easily. Of immediate interest is the conclusion that the current efforts to assemble environmental and land-use databases need not omit data on human behavior and culture.

The COSCA Study

The general objective of the Collaborative Study of Cassava in Africa (COSCA) is to improve the relevance and impact of agricultural research on cassava (Manihot esculenta, also known as manioc or yuca — the main staple of subSaharan Africa) by international agricultural research centers and African national institutions in order to take full advantage of the potential of that crop to increase food production and incomes (Nweke 1988:vii). The principal implementing agency is the International Institute for Tropical Agriculture (IITA) of Ibadan, Nigeria. COSCA is collecting data on farming and food systems in areas where cassava is grown as a staple, beginning in six

*Consultant to the Rockefeller Foundation. 7408 16th Ave. Takoma Park, Maryland 20912

countries with vary high levels of production: Cote d'Ivoire, Ghana, Nigeria, Zaire, Uganda, and Tanzania.

The multidisciplinary needs of the COSCA study determined that data of many types be incorporated. The data are nominal, ordinal, and numeric. The sources include maps, tables, and questionnaires relating to different units and scales. What they have in common is that they all refer to conditions at identifiable places. The data sources are the following:

- baseline map
- maps of physical features (altitude, for example)
- meteorological point data
- administrative boundaries
- cultural/ethnic/linguistic boundaries
- population data, by administrative unit
- agricultural census and survey data, by administrative unit
- transportation route maps (roads, rivers)
- village level patterns: agricultural, economic, social traits
- culture/society level patterns

This data base has had four principal uses in the COSCA study:

1. an independent data base for mapping and analysis
2. a sampling frame for COSCA site selection
3. a source of data to combine with cross-cultural (HRAF) data
4. a source of data to combine with COSCA village-level data

Creation and Use of a Data Base

The initial data gathered as background to the COSCA study were on cassava production and climate, population, and accessibility, three factors thought to determine farming and food systems. The distribution of cassava production in Africa was collated from agricultural censuses and surveys collected in each country. Climate was classified on the basis of length of dry season, daily temperature range during the growing season, and seasonability. Population density was calculated by projecting the latest census figures to 1990. Access was determined by the presence or absence of an all-weather road, railway, or navigable river (Carter and Jones 1989).

The data on these three factors were managed by the agroecological studies unit of the Centro Internacional de Agricultura Tropical (CIAT, a counterpart to IITA) whose Cassava Program is participating in the COSCA study. The map of cassava distribution and the road maps were digitized to create computer images. The administrative boundaries corresponding to census units were also digitized, and the data on population fed to the system. CIAT's climatic database for Africa was used to map the distribution of climatic types.

Manipulation of the substantial data sets that were obtained for site selection required use of a geographic information system. Because of its simplicity and ease of use, the project chose IDRISI, an analysis package developed at Clark University of Worcester, Massachusetts. The African continental image was divided into a grid of cells that would become the framework for mapping

data from the diverse sources available to COSCA.

Each cell was 12' latitude by 12' longitude. Each grid cell was characterized by cassava production, climate type, access, and population density (greater or less than 50 persons per km), resulting in a grid cell or rasterized map of each factor.

In itself, the CIAT database of cassava, climate, access, and population is a valuable resource. For example, a search of population maps for subSaharan Africa revealed only very generalized maps of population density, usually with country-level information. The COSCA map will fill this gap. It is true that the mapped data is only as good as the censuses and projections on which it is based, and some of the data are both out of date and of dubious quality. Because it is based on a computerized database, the map may be updated with ease as new data become available. The map of cassava production revealed unexpected patterns (such as a concentration of cassava in drier zones of East Africa, which at first caused some experts to doubt the veracity of the data) that have since been confirmed by field observation. At the present time, CIAT is analyzing its data base statistically to test hypotheses about the interrelationships among its variables, and CIAT is preparing an atlas of maps for publication.

The following table was produced from the climatic and production figures in the CIAT database. It was used in a paper demonstrating that cassava production is not limited to lowland humid climates and speculating on reasons why there is more cassava production in the dry areas of East Africa than those of West Africa. The climatic classification is based on factors that CIAT Cassava Program thought to be pertinent to the distribution of cassava, and would be adapted to African conditions as COSCA learns more.

Table 1. Area Planted to Cassava in Africa, by Climate Types Based on Factors Pertinent to Cassava Production

<u>CLIMATE TYPE</u>	<u>AREA PLANTED TO CASSAVA</u> <u>('000 HA)</u>
"Sahel-type" Climates:	
Lowland Hot Non-isothermic	360
Lowland Semi-arid Isothermic	386
Lowland Semi-arid Non-isothermic	332
<i>Subtotal</i>	1078
Other Climates:	
Lowland Tropical	2,653
Lowland Subtropical	74
Lowland Semi-hot Isothermic	1,326
Lowland Semi-hot Non-isothermic	287
Lowland Hot Isothermic	754
Highland Tropical	572
Highland Subtropical	17
Highland Andean	129
Highland Brazilian Isothermic	570
Highland Brazilian Non-isothermic	281
Highland Semi-arid Non-isothermic	162
Highland Non-isothermic	71
Highland Semi-arid Isothermic	10
<i>Subtotal</i>	6906
<i>Total</i>	7984

The map of cassava production that follows is taken

(Source: Unpublished data, CIAT, Agroecological Studies Unit, P. Jones and J. Fairbain; classification by Simon Carter 1986).

from the COSCA site selection report (Carter and Jones 1989).

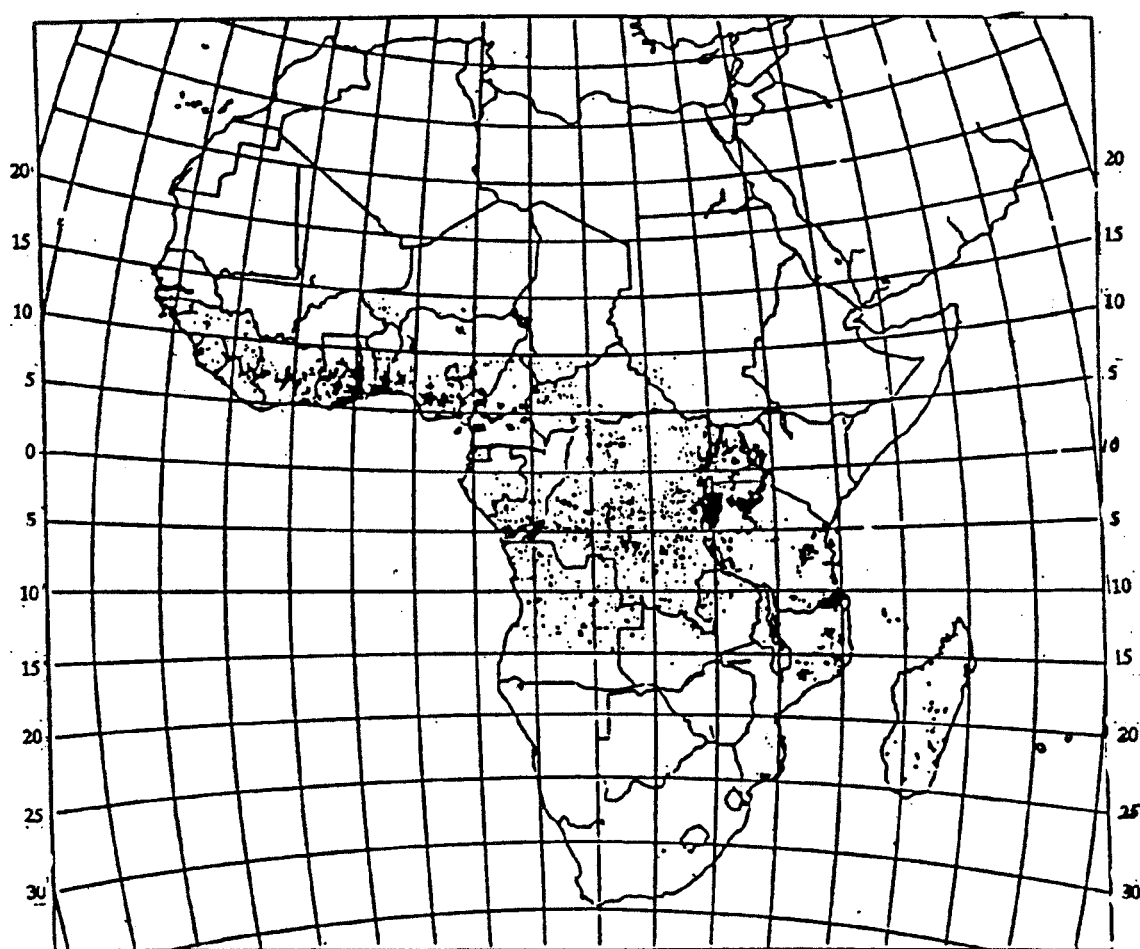


Figure 1. Distribution of Cassava in sub-Saharan Africa (each dot represents 1000 ha)

Sampling

Taking the presence of cassava into account, the CIAT maps became the frame for selecting places to survey. The computer program overlaid the images of individual variables to create new maps of areas with homogeneous climatic, demographic, and access conditions (Figure 2). Within each of the participating countries, grid cells were selected from the uniform areas. Then detailed maps were obtained, and the grid drawn onto the map. The village closest to the center of the grid cell became the sample village for COSCA.

The geographic information system overlaid the thousands of grid cells and mapped them automatically. Such a task would have been extremely difficult had it been undertaken by hand.

Use with Cross-cultural Data

In preparation for the actual village-level survey, COSCA commissioned a preliminary study of a sample of African cultures. The goal was to code 40 cultures (or representative villages) for

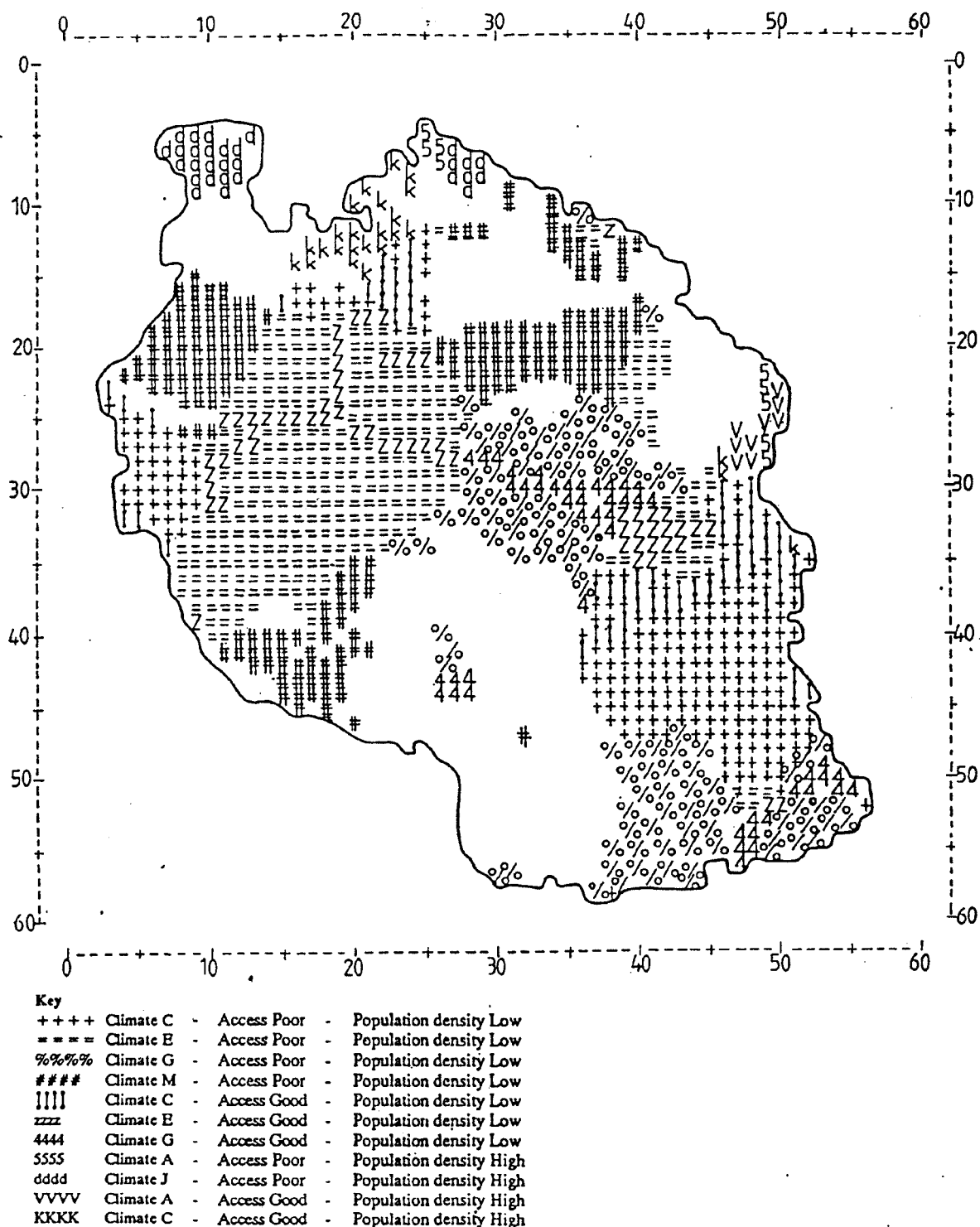


Figure 2. Tanzania: Potnetial survey regions

agricultural practices, use of cassava, and various social traits thought to be relevant to agricultural development. Among those variables were population density (Boserup 1965). The data were to be recent enough to be relevant to current conditions. It was presumed that literature searches would be sufficient to code the cultures, since the traits were not esoteric. The contract was given to the Human Relations Area Files (HRAF) of New Haven, Connecticut.

In fact, the literature search was not successful. HRAF judged that current general-purpose ethnographies with basic data on agriculture, diet, and social organization (either published or as theses) are not as common as they had thought. Nor was it possible to discover a current ethnic or tribal distribution map for geographic analysis.

In light of these difficulties, HRAF switched methods: instead of a literature search, it sent questionnaires to anthropologists who had worked in each of the selected cultures. Completed forms were received from 22 respondents. To map the cultures, CIAT used the only uniform map available that had clear boundaries: Murdock's 1955 effort. Beside the questionnaires, each society was coded using the data from the CIAT data base, already described.

The data were analyzed by correlating variables to test cross-cultural hypotheses from both anthropology and agricultural specialists. The analysis used variables from the CIAT data base, variables from the questionnaire, and indices that mixed data from both sources.

The following are examples of how theoretically relevant variables were operationalized:

- Population density was calculated both from the database and from estimates made by anthropologists.
- Agricultural stress conditions were indexed using number of dry months (from data base), soil quality problems (from maps put on the data base), and fallow periods (from questionnaire).

Table 2. Societies in the HRAF Sample

<u>Group</u>	<u>Country</u>	<u>Region</u>	<u>Language family</u>
Akam	Ghana	West Africa	Kwa
Azande	Zaire	Central Afr	Adamawa-Ubangi
Babua	Zaire	Central Afr	Bantu
Bakongo	Zaire	Central Afr	Bantu
Central Bantu	Zaire	Central Afr	Bantu
Chagga	Tanzania	East Africa	Bantu
Gbaya	Cameroon	West Africa	Adamawa-Ubangi
Rundi, Rwanda	Rwanda,B,Z	East Africa	Bantu
Guan	Ghana	West Africa	Kwa
Igbo	Nigeria	East Africa	Kwa
Ijo (Ijaw)	Nigeria	West Africa	Kwa
Kamba	Kenya	East Africa	Bantu
Kikuyu	Kenya	East Africa	Bantu
Lugbara	Uganda	East Africa	Sudanic
Luo	Kenya	East Africa	Sudanic
Madi	Uganda	East Africa	Sudanic
Mangbetu	Zaire	Central Afr	Sudanic
Mbeere	Kenya	East Africa	Bantu
Nso	Cameroon	West Africa	Bantu
Tabwa	Zaire	Central Afr	Bantu
Yoruba	Nigeria	West Africa	Kwa
Zigva, others	Tanzania	East Africa	Bantu

- Cassava planting was operationalized as a percentage of the total land area, calculated by the data base.
- On the other hand, the index of the dietary importance of cassava used 3 variables from the questionnaire, as follows:

<u>Variables:</u>	<u>Values :</u>
Cassava in diet	prohibited/ not used/ used as a compliment/ supplement/ one of several staples/the primary food
Cassava calories	estimated range as % of total
Predominance of	cassava vs. number of staples (cassava)

- The index of diversity of food strategies in obtaining food used nine variables:

Bring food on roads
 Bought food during hunger period
 Government assistance during hunger period
 Migration during hunger period
 Cattle used for meat, milk, products, drought insurance
 Production of any grain
 Multiple staples
 Multiple cash crops
 Agricultural wage labor (number of tasks)

- Finally, the index of land ownership by kinship groups used 4 variables:

<u>Variables:</u>	<u>Values:</u>
Kin group ownership	common/not
Kin allocates use	yes/no
Individual owns	common/not
Ind. owner operates	yes/no

These variables and indices were used to test a set of hypotheses. The following are a sample.

Hypothesis 1. "Cassava as Intensification" Cassava reliance relative to other crops (contribution to the diet and occupation of the land) should increase with population pressure (density adjusted for length of dry season) on agricultural resources.

Hypothesis 2. "Food Diversity and Cassava" Cassava will be more important where there are fewer food-getting strategies (less of a mix of subsistence strategies, wage labor, cash crops, government supplies, etc.); in turn, this diversity will be positively associated with such cultural and ecological variables as markets, access to markets, population density, and more elaborate technology.

Hypotheses 3a. "Kinship and Cassava" Societies in the cassava belt of Africa with land-holding kinship groups rely more on cassava than do other societies. The cultural and ecological factors that create the market economy are inimical to the continuing existence of such societies. These are proximity to market towns (or transportation) and population pressure.

Hypothesis 3b. Matrilineality and cassava use are positively related.

Hypothesis 4a. Processing technology or effort is a determinant of production levels.

Hypothesis 6. "Labor Limitations on Processing" Where women assume an extreme number of arduous agricultural tasks with less male involvement, they perform fewer processing tasks.

The results of testing the hypotheses were interesting and useful for suggesting hypotheses to test on the larger COSCA database; they are reported in forthcoming publications. For this presentation on the use of Geographical Information Systems, the notable feature is that it was possible to test many hypotheses, in spite of the small sample size. The method of using societies as the basic unit is finer than that of using whole nations (Binswanger and Pingali 1988) and the inclusion of climatic and population data represents an improvement over current cross-cultural studies (e.g. White et al. 1981). The cost of the study was high and its delays substantial, but the methods can be applied more efficiently.

In the future, it may become normal procedure to code societies with environmental data in all cross-cultural surveys that use ecological hypotheses. The methodological questions are not trivial, but the results would add a new dimension of analysis to many studies.

Combinations with COSCA Village-level Data

When the national COSCA teams visited the villages selected according to the procedure already described, they conducted two simultaneous group interviews lasting several hours. One interview concerned agricultural production, the other processing, consumption, and general features of the village. The interviews were long because the effort and cost of reaching a village and gaining permission to conduct a study were so great in many of the countries selected. In countries where access is unrestricted and roads are good, the interview may be shorter.

So far, there have been only preliminary analyses of the data. The next table serves to illustrate how mapped data on population density was mixed with the results of a survey question. The second shows the mix of an agricultural survey question with a social survey question.

Table 3. Crosstabulation of Population Density and Trend in Growing Cassava

		Cassava Trend			Row Total
		Decrease	No Change	Increase	
Population	1	45	2	60	107
	Low				49.5
High	2	19	1	89	109
					50.5
Column		64	3	149	216
Total		29.6	1.4	69.0	100.

Chi-Square D.F. Significance Min E.F.

16.52303 2 .0003 1.486

*Missing Observations = 17

Table 4. Crosstabulation of Main Crop by Lineality of Land Inheritance

	Inheritance			Row Total
	Patriline	Bilateral	Matriline	
Main Crop	1	0	3	4
SHORT TERM CROPS	2.1	1.2	.7	1.9%
GRAINS	31	27	3	61
	32.0	17.7	11.3	29.0%
YEAR CROP	53	25	29	107
	56.0	31.1	19.9	51.0%
TREE CROP	25	9	4	38
	19.9	11.0	7.1	18.1%
Column Total	110	61	39	210
	52.4%	29.0%	18.6%	100.0%

Chi-Square	D.F.	Significance	
28.15918	6	.0001	Number of Missing
Missing Observations = 23			

Among the variables revealed to be spatially patterned by the village level surveys were the timing of hunger seasons and the crops used to alleviate hunger. The months when hunger begins, and the agricultural calendar in general, seem to be related to the movement of the intertropical convergence front. This is a dramatic opportunity to combine village level data with satellite imagery to verify a pattern that is practically relevant.

CONCLUSION

Geographic information systems are a labor-saving tool for combining many kinds of information with those already familiar to anthropologists. In the case of the COSCA study, a cross-cultural survey and a village-level survey integrated information on culture with environmental data to describe patterns and to test hypotheses.

The methods sketched here are becoming so feasible that they will be used commonly in the near future. Issues of data quality will be compelling, as it becomes almost too easy to combine general maps of social data (e.g. Davies 1973) without appropriate verification on the ground. The usual issues of cross-cultural surveys, such as choice of indices and sample bias, will continue to be debated. The sampling and cost experiences of the COSCA study will be pertinent to this discussion of using GIS in cross-cultural studies.

New methods will be incorporated. The COSCA experience indicates no barrier to incorporating satellite imagery with cultural and social data in a single data base. Indeed, we have noted one potential use of practical importance. The requisite to ground truth future data bases will require

substantial effort. One possibility that allows for verification at reasonable cost is establishment of a sample of social, cultural, and agricultural observation sites on a continental scale, comparable to meteorological stations.

REFERENCES

Boserup, Ester , 1965. *The Conditions of Agricultural Growth; the Economics of Agrarian Change Under Population Pressure*. Chicago: Aldine

Carter, Simon and Peter Jones, 1989. *COSCA Site Selection Procedure*. Collaborative Study of Cassava in Africa Working Paper No. 2. Ibadan, Nigeria: International Institute of Tropical Agriculture.

CIAT, 1989. Unpublished tables generated by the Agroecological Studies Unit. Cali, Colombia: Centro Internacional de Agricultura Tropical.


Davies, H.R.J., 1973. *Tropical Africa: An Atlas for Rural Development*. Cardiff: University of Wales Press.

Grandin, Barbara ,1989. Adding community-level variables to FST: a research priority. IN. *Social Science Perspectives on Managing Agricultural Technology*, edited by David Groenfeldt and Joyce Lewinger Moock. Colombo, Sri Lanka: International Irrigation Management Institute, pp. 97-112.

Nweke, Felix, 1988. *COSCA Project Description*. Collaborative Study of Cassava in Africa Working Paper No. 1. Ibadan, Nigeria: International Institute of Tropical Agriculture.

White, Douglas R., Michael L. Burton, and Malcom M. Dow, 1981. Sexual division of labor in African agriculture: a network autocorrelation analysis. *American Anthropologist* 83:824-84.

omit
to
END



APPLICATIONS OF SPACE-AGE TECHNOLOGY IN ANTHROPOLOGY

Discussions

COMMENTS ON THE NASA-SPONSORED SESSION ON REMOTE SENSING AT STENNIS SPACE CENTER, NOV. 28, 1990

Emilio F. Moran*

INTRODUCTION

The various presentations today highlight how quickly ecological anthropologists have responded to the promise held by Remote Sensing technologies and Geographic Information Systems (GIS), since the conference organized by Shankman, Gross and Sever in 1987 at Boulder, Colorado.

Human ecological studies have typically focused on extremely detailed studies of small populations (Baker and Little 1976; Jamison et al. 1977; Rappaport 1967; Netting 1968 and 1981 to name just a few). The virtue of these studies has been that they could quantify in exquisite detail the numerous components of a local ecosystem. They shifted the emphasis away from vulgar correlations of "environmentalism", "possibilism" and other sorts of "determinisms". In so doing they moved us toward more specific and integrative studies emphasizing patterns of mutual causality (Ellen 1982). Their limitations derived from the very source of their strength: the highly localized nature of the data made it difficult to be certain whether the quantified processes applied to other local populations dispersed in time and space.

The traditional training of ecological anthropologists has not prepared them to deal with data sets at the regional level. The training of most currently practicing ecological anthropologists has emphasized biological and field ecology, rather than geography and geophysics. As a result, developments in physical geography and geology were overlooked as to their relevance to anthropological analysis. In the meantime, developments in these two fields now make it possible to link regional data to ground-level local processes.

If ecological anthropology is to achieve its potential, it is important that it become capable of incorporating these new means of linking our powerful but highly localized ethnographic techniques to spatially and temporally more inclusive methodologies. The growing globalization of the environmental problems faced by humankind requires an ability to move from the local to the regional, and from the regional to the global. This means that anthropologists with experience in local level processes of environmental change need to increase their capacity to take part in contemporary debates over how to address current environmental problems.

Recent shifts in the field of ecological anthropology suggest that the extension of research methods to regional scales will be both necessary and welcome. To engage contemporary environmental issues purely at the local level will result in the inevitable marginalization of anthropology from the research and policy circles that have been created to deal with these problems (Rappaport 1990; Moran 1990). Training that extends ecological anthropologists' methodological expertise is one way to ensure that the results of research are taken seriously by colleagues in other disciplines and by policy-makers. In several of the papers today we see the fruits of this engagement by ecological anthropologists in the new technical means to link local to regional--a product of the support by the

*Indiana University, Bloomington, IN.

National Science Foundation, and other sources, in the future of human ecological studies.

Important Questions Asked

The papers by George Morren and Bruce Winterhalder note the importance of moving discussion of ecological adaptation from the village-level to more generalized levels within a larger spatial and temporal scale. For example, how is the 75% abandonment of terraces in the Andes related to slope, to distance to various types of water sources, to distance from settlement location, and to the size-classes of settlements?

Remote sensing technologies allow us to look at micro-ecological adaptation to specific classes of resources such as forests, water courses, soil types, etc. One of the concerns of many anthropologists still unfamiliar with GIS and remote sensing is that these approaches will distance us from the people we study--that we will become laboratory researchers and not field scientists. The papers at this conference repeatedly showed that the constant need to check unsupervised image classifications and process on the ground (i.e. ground-truth) will keep bringing us back to the field and, thus, to our subjects of study and their behavior toward the physical environment.

These new technologies allow us to make powerful connections within a region and between regions--as exemplified by Payson Sheets's discovery of foot paths in Costa Rica--and as shown in David Wilkie's ability to distinguish between gold camps and agricultural settlements. The latter had importance in terms of deciding on the location of protected reserves.

Perhaps most exciting of all is the possibility of tracking demographic, physical environmental, and agricultural change over time and space. Many questions of anthropological interest suggest themselves immediately that relate, for example, to better understanding change in settlement size, in crop area, and even in crop mixes. Are these changes related to historically-verifiable processes of world price shifts in commodities? To political interventions by the state in a region, such as would occur with road building and credit schemes? The success of GPS receivers reported by Wilkie, Chagnon, and Baksh/Behrens bodes well for our future fieldwork, as does the tendency of these receivers to become increasingly downsized and lightweight.

I have heard a number of colleagues in cultural anthropology express grave doubts about the possibility of keeping our distinctiveness and proximity to people in the process of becoming users of remotely sensed data. Will our remotely-sensed data make us increasingly remote from people? I beg to differ with these colleagues, as I suspect most of us here would.

Listening to Napoleon Chagnon, for example, immediately suggested to me how one might be able to tackle a number of provocative questions that he raised long ago: about the relative role of political vs environmental factors in explaining the pattern of Yanomamo settlement, the patterns of fissioning, and the pattern of warfare. The Yanomamo occupy a region that includes montane forest, pre-montane forest, savannas of variable quality, bana/caatinga xeromorphic vegetation on impoverished white sandy soils, downsized upland tropical forest on oligotrophic oxisols, and probably some patches of alluvial floodplains--some poor (on black water rivers) and some richer on a couple of the white-water rivers crossing their territory.

Are the core areas of the Yanomamo on the few patches of better soils in the otherwise "sea of poverty" that characterizes such drainage basins? Are the peripheral Yanomami settling in these poor areas and finding that they are unable to find adequate sustenance in them? These provocative hypothetical relations can be tested by using GIS and layering the villages' movements on top of mapped landscape features (soils, slopes, etc). These hypothetical relations will, in turn, generate questions that only additional fieldwork can answer for particular sampling areas and inform the next regional analysis of processes.

The provocative paper by Fred Limp, enhancing the usefulness of the site catchment model, allows for further connectedness between lab work and field work. For example, the hypothesis that the cost of moving from one square to another on a given degree of slope goes up as the square, rather than as a linear function, can be tested by using respirometers under those particular field conditions being modeled by GIS. These field findings can, in turn, permit sharpening of the equations used to refine the catchment model. To what extent are the increased costs of moving along space to harvest resources related to the patchy dispersal of resources, to levels of demographic pressure experienced?

Advances Already Made in Matters of Method

Despite the recent start of several of the projects reporting here, there is evidence already of attention to questions of method and refining the accuracy of the measures taken:

1. The suggestion by Baksh that the use of an altimeter in the field may be more accurate than relying on the reading from a GPS receiver is worth noting, as is the quicker rate of reading latitude and longitude if one inputs the altitude information in advance.
2. The importance of taking multiple (15) fixes at a given site in order to obtain a more accurate and reliable measure and the importance of paying attention to "high geometric quality" as an indirect measure of accuracy deserves attention in future studies. This comes as no surprise to me, given that the same phenomenon occurs in taking soil samples. The "ideal" number of cores for a single soil sample in a homogenous field is about 15. One should take note that this general standard should not be used uncritically. In soils of the tropics, if the questions being asked relate to phosphorus, it may be necessary to take up to 45 cores in a given soil sample given the low levels of phosphorus to be found, their patchiness in a given field, and the fact that this tends to be the most limiting nutrient in humid tropic areas. The 15 fixes suggested by Baksh present us with a useful guide, but the precise standard will require attention by future field workers to comparisons in results as presented by Baksh in his paper.
3. Several of the papers raised the problems since the early 1980's by the privatization of Landsat images and their high cost to researchers. The importance of communicating with legislators and others about the negative consequences from this reduction in research usage deserves more attention in the years ahead.
4. The lack of established signatures for heterogeneous areas like the Amazon and the Congo Basins is still problematic and should become a focus of field research. On the other hand, Wilkie's paper served to remind us that in many tropical rain forests there are at times single-specie dominants that

should give a clear signature visible in TM and MSS for up to 10 or 15 years. Cecropia in portions of the Amazon dominates for at least five years, in like fashion.

5. The problems encountered by Baksh with the GPS unit suggests that the downsizing of receivers should not occur at the expense of ruggedness in the field. It will be important to communicate with companies developing these technologies that ruggedness is fundamental to the effective use of this kind of equipment.

6. Winterhalder correctly pointed out that GIS work is still largely experimental and requires more time than many of its promoters like to acknowledge. On the other hand, the interactive and iterative nature of this kind of work allows the continuous modification of the questions asked and the testing of relationships entirely new to the original design of the study.

7. The accuracy of sideways-looking radar, due to distortions, was questioned by Napoleon Chagnon and is a troubling one. It may require considerable work to correct this more fine-grained data to permit layering it with the Landsat scenes in such a way as to be productive.

CONCLUSIONS

Application of remote sensing technologies to questions of ecological and anthropological import demonstrates that the future is promising and that many hypothetical relations that remain untested may be subject, at last, to verification. While the cost of time in setting up these kinds of analyses may be high, once the data have been put into the computer, they permit an unlimited number of transformations that allow one to test counterintuitive processes normally too costly to even try. Since there is evidence that the behavior of complex systems is often counterintuitive, this advance in analytical procedure promises to let us begin to treat human behavior and ecological adaptive processes with the complexity that they deserve.

REFERENCES

Baker, P. and M. Little eds. 1976. *Man in the Andes*. Stroudsburg, PA: Dowden, Hutchinson and Ross. US/IBP Human Adaptability Monograph #1.

Ellen, R. 1982. *Environment, Subsistence and System*. Cambridge: Cambridge Univ. Press.

Jamison, P. et al. 1977. *The Eskimos of NW Alaska*. Stroudsburg, PA: Dowden, Hutchinson and Ross. US/IBP Human Adaptability Monograph #2.

Moran, Emilio F. 1990. *Ecosystem Ecology in Biology and Anthropology: A Critical Assessment*. in *The Ecosystem Approach in Anthropology: From Concept to Practice*. Edited by E. F. Moran. Ann Arbor: Univ. of Michigan Press.

Netting, Robert. 1968. *Hill Farmers of Nigeria*. Seattle: Univ. of Washington Press. AES Monograph.

Netting, Robert. 1981. *Balancing on an Alp*. New York: Cambridge Univ. Press.

Rappaport, Roy. 1967. Pigs for the Ancestors. New Haven: Yale Univ. Press.

Rappaport, Roy. 1990. Populations and Ecosystems. in The Ecosystem Approach in Anthropology: From Concept to Practice. Edited by E. F. Moran. Ann Arbor: Univ. of Michigan Press.

DISCUSSION

James Wiseman

The first national conference on remote sensing in archaeology was held here in the Space Center some six years ago. The chief aims of that conference were to introduce remote sensing technology to a number of archaeologists working in many different parts of the world and dealing with a great variety of research concerns, and to set up some realistic goals for archaeological and anthropological applications of the new technology. One hope for the future then was that the new technological tools would prove to be especially useful in regional studies, on a scale and in detail not previously possible, of relations between ancient societies and their environmental settings. Participants in the conference also hoped to encourage a network of communication among interested scholars, and to seek ways of interesting both U.S. Government and private funding agencies in supporting such research. It seemed particularly important to the realization of some of these aims to develop model projects.¹

The conference today included presentations not only of archaeological research very much along the lines hoped for in 1984, but also of social-cultural anthropological research. It has also been particularly gratifying to hear the report by Payson Sheets on the project selected by a committee of that first conference to receive NASA support for the remote sensing component of the proposed research. The research design and fieldwork by Payson Sheets, Tom Sever, and their colleagues serve as distinguished a model as the participants in the first conference had hoped.

The papers presented today represent major steps along the way towards integrating remote sensing technology into the standard toolkits serving archaeological and anthropological research. Indeed, as our hosts have pointed out, even more papers of importance could have been presented if the conference had been scheduled for two (or three!) days instead of one. I might mention as just one example, a project headed by Larry Banks, a participant in the 1984 conference, which was carried out in a group of eight states and involved remote sensing and geographic information systems, with significant results in predictive modelling of archaeological site location. I will look forward to hearing more about that project, as well as the others that could not be accommodated in the present schedule.

Given the large number of papers, and the rich substance of the reports by the speakers, the organizers of today's conference were wise to apportion the discussion between two of us. I am honored to share the assignment with Emilio Moran, and will limit my remarks mainly to the papers dealing especially with applications in archaeology. The papers touched on a variety of topics, many of which may be grouped under the following three headings for the purposes of discussion; I will not try to discuss all the contributions of each paper.

¹ The 1984 conference was funded by NASA, the National Science Foundation, and the National Geographic Society; see Thomas Sever and James Wiseman, *Remote Sensing and Archaeology: Potential for the Future. Report on a Conference, March 1-2, 1984* (NASA, Earth Resources Laboratory, 1985).

Geographic Information Systems (GIS)

Several papers stressed the importance of GIS in archaeological research. Fred Limp, who has been at the forefront of GIS development in archaeology, offers some convincing evidence for the practical effectiveness of GIS in his development of the Continuous Cost Movement Model. The model is viewed by Limp as a retrieval of site catchment analysis from theoretical disrepute by means of methodological developments in GIS. His argument is commendable, although he seems to overstate the problems of earlier site catchment analysis involving linear catchments. In that regard we might look, for example, to the successful linear catchment analysis of sites in the Oaxaca valley by Kent Flannery.

Clifford Behrens introduced us to a methodology that has wide applicability. In his work on the cultural ecology of the Amazon, he used cluster analysis and sliding color techniques to assist in the detection of areas of interest. He then proceeded to employ GIS to effectively discriminate different uses of land in the areas of interest; for example, agricultural fields in use or lying fallow, and the discrimination of different types of crops. I suspect that most of us can join Behrens in his call for equipment capable of providing 20-meter resolution on space platforms.

By his work in the Black Prairie, Jay Johnson demonstrated one of the more significant contributions GIS makes to archaeological research. I refer here to the capability scholars have through GIS of moving to different overlays of data, and to different combinations of such data as soils, rivers, and zones of development. Johnson established especially well the useful results of being able to review at the regional data in different ways.

Geophysical Approaches

The paper by James Doolittle and Frank Miller provided sound advice on the use and effectiveness of ground-penetrating radar (GPR). The report, illustrated with case studies, had a particular ring of authority since it was based on their work in 43 (an astounding number!) states and abroad. In one instance they used GPR to distinguish, without excavation, a possible Indian mound from a dune along a river. They also argued, however, that ideally GPR survey should be supported by some amount of excavation. Another instance demonstrated how effective GPR can be in some circumstances: at one site, nine internal features detected by GPR were subsequently confirmed by precisely nine test excavations. They also point out that interpretation of GPR data should be carried out in the field, so that anomalies can be checked at once (often impossible to do once the surveyors have returned to their base). They point out that there is nothing to gain, in any case, by delaying interpretation for the lab, and confusion is often the result.

The case studies and their other observations make a strong case for the high value of GPR in archaeological research. They announced that both GPR and archaeologists with the expertise to operate them and interpret the data, are available for collaborative work from the Soil Conservation Service. I would add that both equipment and personnel are available for such collaboration through other organizations, including the Center for Remote Sensing at Boston University.

Payson Sheets reported on the broad array of geophysical techniques used in El Salvador and

Costa Rica; his comments on their comparative usefulness are of particularly benefit. Magnetometers were of no use in volcanic terrain. Seismic refraction yielded few results for a great deal of time invested; the technique seemed best for deeply buried features. Electric resistivity, on the other hand, was quick and easy to use and had good results, but only in dry land and with other special conditions. Such comparisons and reports of tests in different environmental settings are especially valuable to other researchers in planning what equipment should be taken on a particular project. In the first place, as both Sheets and Doolittle emphasized, some devices will yield no useful results in certain settings (e.g., radar in very moist or clayey soils). Others may be simply too complex for transport to and use in the particular region, the GPR used by Sheets had to be sent to Central America in seven separate crates!

Imagery

Sheets also was able to offer valuable comparative results of remote sensors mounted both on aircraft and spacecraft. Few archaeological projects have ever made such extensive use of remote sensing devices and imagery. The most productive aircraft-mounted devices used in Central America proved to be a conventional camera with color infrared film, and the Thermal Infrared Multispectral Scanner, (particularly for linear anomalies). Sheets and his colleagues found that aircraft-mounted radar was very powerful, but difficult to understand and that it provided indications of far more anomalies than could be readily investigated. He provided little information on Lidar, a more recently developed technique that is being used for the first time in archaeology.

TIMS is also proving of major benefit in archaeological site reconnaissance in the Peten of northern Guatemala. In the paper by Frank Miller, Thomas Sever, and Daniel Lee we learned that TIMS, at 5-meter resolution, is proving to be particularly effective in the detection of sites because of its capabilities in recording linear anomalies. The project is also contributing new models for the prediction of sites. It is unfortunate that aircraft-mounted TIMS is not more widely available to archaeological research projects, since its effectiveness is so clearly demonstrated.

B. C. Cullen and F. A. Cooper reported on one of the rare projects to employ remote sensing technology in Greece. They have been particularly interested in developing spectral signatures for certain kinds of sites, and have concentrated so far on ancient quarries. They made salutary remarks about the limitations of simple surface survey, unaccompanied by any kind of remote sensing, and provided some illustrations of the value of aerial photography from a tethered blimp. Their argument against widespread deforestation in ancient Greece was less satisfactory, since it is based on the detection by imagery and ground-truthing only of present forest, which could conceivably be relatively recent in origin.

We owe our thanks to Bruce Winterhalder for calling our attention to a problem seldom mentioned in literature, and yet of considerable importance for scholars working in areas of greatly varying topographic profile. There is a difference, he emphasized, between map area and surface area, and that difference is often overlooked in reports. He then went on to explain how to determine the actual surface area in computer images by factoring in slope and aspect in a three-dimensional graphics program. The technique is useful and the information thus acquired can be of great significance in the analysis, for example, of the utilization of terraced fields on mountain slopes.

Conclusions

Advances over the past six years in the application of remote sensing technology to archaeological and anthropological research, as reported at the conference, are in some ways astonishing; we seem to have come very far in a short period of time. There is still a need, however, for broader accessibility to instructional programs in remote sensing and in GIS, both for students and for advanced scholars; there are few programs anywhere in the country that emphasize or even encourage their application in archaeology and anthropology. In research, archaeologists need to be able to acquire data at finer resolution than 20 meters. As Jay Johnson commented in his talk: "The nice thing about 5-meter data is that you can really see something." Tethered blimps can be used for close work and they make adequate platforms for some sensors, but the kinds of sensors they can carry are limited, as is the range the balloons can effectively cover. Readier and less costly access to aircraft-mounted TIMS would be a great boon to archaeological research.

Although advances in methodology have often been seized with alacrity, there has been a slowness by the majority of our colleagues to recognize the value of the methodology, or that it can affect theoretical concepts. The latter seems to lie behind the reluctance of the American Anthropological Association and the Archaeological Institute of America to schedule sessions on remote sensing. There has been a concern voiced from time to time (including at the 1984 conference) that the techniques might be adopted in some mindless way for the sake of the techniques, and that the quality of the research design and aims might be ignored. If such a worry actually persists among some of our colleagues, I wish all the more that they had been able to hear the papers of this conference; that worry would have been dispelled. The problem, however, may merely be that too few projects involving remote sensing have yet had broad exposure in our scholarly journals; if so, that problem is likely to be remedied soon through the publication of some of the projects we have been hearing about today. We might also follow up on a suggestion that came from several sources today, and develop an annual conference on remote sensing in archaeology and anthropology.

Finally, I wish to thank Clifford Behrens and Tom Sever for organizing this conference, and NASA for hosting it. We have all, I am confident, learned much that we can use to good benefit in our own research.